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ENVIRONMENTAL EFFECTS MONITORING FOR EXPLORATION DRILLING

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Calgary, Alberta
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ENVIRONMENTAL EFFECTS MONITORING FOR EXPLORATION DRILLING

by

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Executive Summary

Introduction

This study was conducted for the Environmental Studies Research Funds (ESRF) by a Study Team composed of LGL Limited, CEF Consultants Ltd., and Oceans Ltd. The primary goal of the study was to develop a strategy for monitoring environmental effects at a single exploratory offshore well on the East Coast.

At present, there are no specific environmental effects monitoring (EEM) requirements for drilling exploratory wells offshore on the East Coast. In the Canadian Arctic, there may be requirements to conduct marine mammal monitoring depending upon location and season. For the most part, environmental protection is achieved through the environmental assessment/permitting process and a series of generic and project-specific mitigations.

The work consisted of consultations with scientists, regulators, and stakeholders, reviews of regulatory regimes, toxicity results relevant to exploratory activities, and East Coast production EEM programs, and development of a 'decision tree' for determining when to conduct EEM, and at what level of effort, and some suggested study design considerations.

Issue Scoping

Issue scoping was conducted by reviewing the results of previous East Coast environmental assessments and any associated comments by reviewers and stakeholders. Subsequently, a series of informal consultations were held with individuals from Fisheries and Oceans, Environment Canada, the Canada-Newfoundland and the Canada-Nova Scotia offshore regulatory boards, the fishing industry and environmental interest groups.

Results of consultations varied from 'monitor everything' to highly focused specific detail. There were a number of differences between the two regions in the perception of issues with the main ones perhaps being greater interest in benthos (e.g., shellfish and corals) and marine mammals (e.g., 'The Gully', a potential marine protected area) in Nova Scotia versus a greater interest in fish/fisheries and marine birds in Newfoundland. Nonetheless, there were at least eight general areas of commonality:

1. **Level of concern.** Most respondents had a much lower level of concern for the single exploratory well than for a production development.

2. **Assurance.** While a number of scientists argued for full statistical treatment of all data, there was a common thread with most people that some level of assurance was required that the marine environment was not being unduly harmed, with or without full statistical confirmation.

3. **Biological effects.** Most felt that the focus should be on biological effects rather than some trace chemical 'signals'.

4. **Seabirds and marine mammals**. Many agreed that birds and mammals deserved attention and that any existing supply boat or rig observations were viewed positively; however, concern was addressed about the value of the data in terms of actually monitoring the effects of exploratory drilling activities.

5. **Data availability.** Data availability was expressed as a concern with virtually everyone that we consulted.

6. **Site specifics.** Local and site-specific issues must be considered in the design of any EEM.

7. **Cumulative effects.** Many were concerned about potential cumulative effects with other industrial activities although no one had any particularly valuable insight into how to handle exploratory wells within this context.

8. **Testing EA.** A number of respondents suggested that test case (s) be established and monitored not only to test EA predictions but also to establish scientific rationale for inclusion or exclusion of specific variables in future EEM programs.

Information Reviews

Regulatory Regimes

Different jurisdictions regulate exploratory drilling differently but few jurisdictions have specific EEM regulations aimed at the single exploratory well. For example, in the Gulf of Mexico, regulators have relied on some large-scale research programs (i.e., 'case studies') and a zoning approach to protect the environment. In Alaska, permit requirements can be complex and there is often some form of marine mammal monitoring because of concerns related to endangered bowhead whale during the summer and ringed seal disturbance in the winter. There are few, if any, EEM requirements for an exploratory well in offshore West Africa, Brazil, or Indonesia. On the East Coast of Canada, there has been reliance on the EA and permitting processes and compliance monitoring to the *Offshore Waste Treatment Guidelines* to protect the environment during exploratory drilling. However, as of the 30th of October 2003, there is a *Canadian Environmental Assessment Act* (*CEAA*) requirement for some form of 'follow-up' to *CEAA* environmental assessments (including screening level ones), which could include EEM.

Toxicity Effects

Baring accidental events, the primary discharges of potential concern during exploratory drilling are drilling muds and cuttings which are regulated under the *Offshore Waste Treatment Guidelines*. On the East Coast, water-based-mud (WBM) is now the most commonly used drilling fluid; synthetic-based-mud (SBM) may also be used in certain situations. Modern muds are now essentially non-toxic although some pathological effects of barite (barium sulfate, a major constituent of drilling mud) have been reported during laboratory tests with scallops, shrimp, and flounder. The main environmental effects of the discharge of mud and cutting are probably some very localized smothering an/or alteration of benthic communities near the well. Cuttings with WBM tend to disperse more widely than those with SBM which tend to clump near the well.

State of the art methodology for monitoring the potential effects of drilling discharges include benthic community structure, sediment bioassays, mixed function oxygenase (MFO), and histopathology.

East Coast Production EEM

Large scale EEM programs for offshore production developments on the East Coast are being conducted for the Sable Offshore Energy Project (SOEP) and Cohasset Panuke off Nova Scotia, and Hibernia, Terra Nova and White Rose off Newfoundland. Variables measured, numbers of samples, intervals sampled, and study designs have varied somewhat between the projects. Common variables have included sediment and water chemistry, toxicity testing, benthic community structure, fish or shellfish taint, and fish health. The study design is normally some sort of radial design with sampling at increasing distances from the source, sometimes with provision made for prevailing water currents. In most cases, effects, if any, have been confined to within a 500 m radius of the rigs. This is consistent with the most recent reports from the North Sea and the Gulf of Mexico. The primary lessons for designing an EEM program for an exploratory well include (1) the 'signals' will be relatively weak and close to the rig, and (2) effects will likely be much less for the single well than for the multi-well development scenarios. In addition, there may be benefit in analyzing existing production baseline and EEM data with the sole intent of detection of effects (or lack thereof) from the original exploratory wells.

Potential Decision Process

A potential 'decision tree' has been suggested for different levels of EEM based on three different scenarios:

(a) Scenario 1—well known area with no sensitive issues. Compliance monitoring but no EEM would be conducted.

(b) Scenario 2—shallow or deep areas with no known sensitive issues. Opportunistic EEM surveys of sediments, benthos, seabirds and marine mammals would be 'piggy-backed' on existing logistics.

(c) Scenario 3—sensitive areas. Custom EEM surveys would be required.

Most EEM for an exploratory well can be 'piggy-backed' onto existing programs such as well site surveys in order to minimize costs.

'Special' EEM support studies of selected existing data and new data could be collected to further refine, and potentially maximize data return while lowering costs.

Résumé

Introduction

L'étude a été réalisée pour le Fonds pour l'étude de l'environnement (FEE) par un groupe d'étude composé de LGL Limited, de CEF Consultants Ltd. et d'Oceans Ltd. Elle visait principalement à élaborer une stratégie de suivi des effets sur l'environnement à un puits exploratoire unique au large de la côte Est.

Pour le moment, il n'existe aucune exigence précise en matière d'étude de suivi des effets sur l'environnement (ESEE) concernant le forage de puits exploratoires en mer sur la côte Est. En ce qui concerne l'Arctique canadien, il pourrait exister l'obligation de réaliser un suivi de la situation des mammifères marins selon le lieu et la saison. Dans l'ensemble, le processus d'évaluation environnementale et de délivrance de permis ainsi qu'une série de mesures d'atténuation générales et propres aux projets permettent d'assurer la protection de l'environnement.

Les travaux ont consisté en des consultations auprès de scientifiques, d'organismes de réglementation et d'intervenants, des examens des régimes de réglementation, des résultats sur la toxicité se rapportant aux activités d'exploration et des programmes d'ESEE concernant la production sur la côte Est, et l'élaboration d'un « arbre de décision » servant à déterminer le moment où il est nécessaire d'effectuer une ESEE, et le niveau d'efforts requis, et certains aspects des modèles d'étude proposés.

Établissement des enjeux

L'établissement des enjeux a été réalisé en examinant des résultats d'évaluations environnementales antérieures menées sur la côte Est et tout commentaire connexe formulé par les examinateurs et les intervenants. Par la suite, des représentants de Pêches et Océans, d'Environnement Canada, des offices Canada – Terre-Neuve et Canada – Nouvelle-Écosse des hydrocarbures extracôtiers, de l'industrie de la pêche et des groupes écologistes ont participé à une série de consultations non officielles.

Les résultats des consultations variaient depuis « tout surveiller » jusqu'à des détails précis très pointus. La perception des enjeux était quelque peu différente entre les deux régions; la principale différence étant peut-être un plus grand intérêt envers les benthos (p. ex., les mollusques et les coraux) et les mammifères marins (p. ex., « Le Gully », une zone potentielle de protection marine) en Nouvelle-Écosse par rapport à un plus grand intérêt envers les poissons/pêches et les oiseaux de mer à Terre-Neuve. Cependant, il y avait au moins huit points communs généraux :

9. **Niveau de préoccupation.** La plupart des personnes interrogées se préoccupaient beaucoup moins du puits exploratoire unique que de la mise en valeur de la production.

10. **Garantie.** Bien que certains scientifiques aient parlé en faveur de l'analyse statistique complète de toutes les données, la plupart des personnes estimaient qu'il devait y avoir un certain niveau de garantie que l'environnement marin n'est pas endommagé outre mesure, avec ou sans une confirmation statistique complète.

11. **Effets biologiques.** La plupart des gens estimaient que l'accent devrait être mis sur les effets biologiques plutôt que sur certains « signaux » chimiques.

12. **Oiseaux de mer et mammifères marins**. De nombreuses personnes ont reconnu que les oiseaux et les mammifères méritaient de l'attention et que toutes les observations provenant de navires de ravitaillement ou d'installations de forage étaient considérées comme positives. Cependant, on a exprimé des préoccupations concernant la validité de ces données pour ce qui est de surveiller concrètement les effets des activités de forage d'exploration.

13. **Accès aux données.** Pratiquement toutes les personnes que nous avons consultées se préoccupent de l'accès aux données.

14. **Enjeux propres au site.** Il faut tenir compte des enjeux locaux et propres au site durant l'élaboration de toute ESEE.

15. **Effets cumulatifs.** De nombreuses personnes se souciaient de la possibilité d'accumulation des effets avec ceux d'autres activités industrielles, bien que personne n'ait présenté d'idée particulièrement valable sur la façon d'exploiter les puits exploratoires dans ce contexte.

16. **Essai d'évaluation environnementale.** Certaines personnes interrogées ont proposé d'établir et de surveiller un ou des cas types non seulement pour tester les prédictions en matière d'évaluation environnementale, mais aussi pour établir les justifications scientifiques de l'intégration de variables précises dans les programmes futurs d'ESEE, ou de leur exclusion.

Examens de l'information

Régimes de réglementation

Les différentes administrations réglementent le forage d'exploration de façon différente, mais peu d'administrations disposent de règlements précis en matière d'ESEE axés sur les puits exploratoires uniques. Par exemple, dans le golfe du Mexique, les organismes de réglementation se sont fiés à certains programmes de recherche de grande envergure (c.-à-d., les « études de cas ») et à une approche de zonage pour protéger l'environnement. En Alaska, les exigences liées aux permis sont parfois complexes et il existe souvent une certaine forme de surveillance des mammifères marins, et ce, en raison de préoccupations en été à l'égard de la baleine boréale, en voie de disparition, et en hiver à l'égard du phoque annelé dont l'environnement est perturbé. Il existe peu, voire pas, d'exigences en matière d'ESEE concernant un puits exploratoire au large des côtes de l'Afrique de l'Ouest, du Brésil ou de l'Indonésie. Sur la côte Est du Canada, on s'est fié aux processus d'évaluation environnementale et de délivrance de permis et à la surveillance de la conformité aux *Lignes directrices sur le traitement des déchets extracôtiers* pour protéger l'environnement durant les activités de forage d'exploration. Cependant, depuis le 30 octobre 2003, la *Loi canadienne sur l'évaluation environnementale* (LCÉE) exige une certaine forme de « suivi » des évaluations environnementales effectuées en vertu de la LCÉE (y compris celles au niveau de l'examen préalable), lequel pourrait inclure une ESEE.

Effets de la toxicité

Sauf en cas d'accidents, les boues et déblais de forage, lesquels sont réglementés en vertu des *Lignes directrices sur le traitement des déchets extracôtiers*, constituent les principaux déchets susceptibles de causer de l'inquiétude dans le cadre d'un forage d'exploration. Sur la côte Est, la boue à base d'eau est

maintenant le fluide de forage le plus couramment utilisé; la boue de forage synthétique est parfois utilisée dans certaines situations. Les boues modernes sont essentiellement non toxiques, bien que des effets pathologiques de la barite (sulfate de baryum, un composant majeur de la boue de forage) ont été signalés lors de tests en laboratoire sur des pétoncles, des crevettes et des plies. Le rejet de la boue et des déblais a probablement pour effet principal l'étouffement ou l'altération très localisés des communautés benthiques situées près du puits. Les déblais extraits au moyen de la boue à base d'eau tendent à se disperser davantage que ceux extraits grâce à la boue de forage synthétique, qui ont tendance à s'amasser près du puits.

Parmi les méthodes de pointe pour le suivi des effets potentiels des déchets de forage, mentionnons la structure de la communauté benthique, les épreuves biologiques de sédiments, les oxygénases à fonction mixte (OFM) et l'histopathologie.

ESEE concernant la production sur la côte Est

Les programmes d'ESEE à grande échelle concernant les projets de mise en valeur de la production extracôtière sur la côte Est sont exécutés dans le cadre du Projet énergétique extracôtier de l'île de Sable et du projet Cohasset Panuke au large de la Nouvelle-Écosse, ainsi que des projets Hibernia, Terra Nova et White Rose au large de Terre-Neuve. Les variables mesurées, le nombre d'échantillons, les intervalles échantillonnés et les modèles d'étude ont varié quelque peu selon les projets. Parmi les variables communes, mentionnons la chimie des sédiments et de l'eau, les tests de toxicité, la structure de la communauté benthique, la pollution des poissons et des mollusques, et la santé des poissons. Le modèle d'étude consiste normalement en une sorte de modèle radial comprenant un processus d'échantillonnage à distances croissantes depuis la source, parfois en tenant compte des courants marins. Dans la plupart des cas, les effets, s'il y en a, n'ont pas dépassé le rayon de 500 m entourant les installations de forage. Il s'agit de données correspondant aux rapports les plus récents concernant la mer du Nord et le golfe du Mexique. Voici les principales leçons à retenir en vue de la conception d'un programme d'ESEE pour un puits exploratoire : (1) les « signaux » seront relativement faibles et près de l'installation de forage, et (2) les effets seront probablement moins importants dans le cas d'un puits unique que des projets de mise en valeur de multiples puits. De plus, il peut être avantageux d'analyser les données qui existent sur la production de référence et l'ESEE avec pour seule intention de déterminer la présence (ou l'absence) d'effets produits par les puits exploratoires originaux.

Processus décisionnel potentiel

Il a été proposé d'utiliser un « arbre de décision » potentiel pour différents niveaux d'ESEE selon trois scénarios différents :

(d) Scénario 1 — Zone bien connue sans enjeu de nature délicate. Il y aurait une surveillance de la conformité, mais aucune ESEE.

(e) Scénario 2 — Zones de profondeur faible ou élevée sans enjeu de nature délicate connu. La réalisation opportuniste d'ESEE concernant les sédiments, les benthos, les oiseaux de mer et les mammifères marins serait superposée aux processus logistiques existants.

(f) Scénario 3 — Zones avec enjeu de nature délicate. Des ESEE sur mesure seraient requises.

La plupart des ESEE pour un puits exploratoire peuvent être superposées à des programmes existants tels que la réalisation de relevés de site afin de minimiser les coûts.

Des études « spéciales » de soutien des ESEE portant sur des données existantes choisies et de nouvelles données pourraient être réalisées pour améliorer davantage et peut-être maximiser la production de données tout en diminuant les coûts.

1.0 Introduction

This study was conducted for the Environmental Studies Research Funds (ESRF) by a Study Team composed of LGL Limited, CEF Consultants Ltd, and Oceans Ltd. The primary goal of the study was to develop a strategy for monitoring environmental effects at a single exploratory offshore well on the East Coast.

1.1. Objectives and Purpose of the Study

Exploration drilling occurs after geophysical (seismic) and other types of surveys have determined the location and extent of a possible hydrocarbon bearing geological formation. Formations identified with remotely collected data may contain commercially viable hydrocarbon deposits or they may contain only water or hydrocarbons in quantities that are uneconomic to develop. Exploration drilling is the only sure way to confirm the presence of viable quantities of hydrocarbons.

In the event that hydrocarbons are found during exploration drilling, testing may be required to further define a prospect's potential for development. Once the presence of hydrocarbons is confirmed by exploratory drilling and associated testing, further appraisal or delineation drilling may be required in order to establish the extent and commercial viability of a prospect.

A number of hydrocarbon exploration wells have been drilled offshore on the East Coast and several are planned in the next few years. Before granting approvals to drill, the Canada/Newfoundland Offshore Petroleum Board (C-NOPB) or Canada/Nova Scotia Offshore Petroleum Board (C-NSOPB) (i.e., the 'Boards') must evaluate the potential environmental effects of each well. Given that many aspects of offshore exploration wells are common to all such wells, a *generic assessment* of the common aspects of offshore exploration wells was conducted in 1999 for Nova Scotia waters (Thomson et al. 2000). In Nova Scotia, drilling applications for specific wells incorporate the generic assessment by reference and address site-specific aspects of the environment, impacts or project activities. In Newfoundland, generic assessments *per se* have not been done but exploration EAs (e.g., Husky 2002 and Husky 2003a) have built on other comprehensive assessments for major production developments such as Hibernia, Terra Nova and White Rose. In addition, a strategic environmental assessment (SEA) of exploration activities was recently completed for the Orphan Basin off Newfoundland and Labrador (LGL 2003).

Some research scientists, non-government organizations (NGOs), and stakeholders have expressed concern over the potential impact of exploration drilling. In addition, the *Canadian Environmental Assessment Act* (*CEAA*) generally requires some sort of follow up or monitoring to validate impact predictions, especially when the predictions are tenuous or viewed to be tenuous. Environmental effects monitoring (EEM) has been carried for large developments such as Hibernia, Terra Nova, Sable Island, Cohasset-Panuke, and White Rose. Simply, EEM can be defined as a test of impact predictions made in an EA or EIS. The purpose of this study was to determine if EEM is required, and if so, in what situations, as well as to provide some guidance in program design.

At present, there are no specific EEM requirements for drilling exploratory wells offshore on the East Coast. In the Canadian Arctic, there may be requirements to conduct marine mammal monitoring depending upon location and season. For the most part, environmental protection is achieved through the environmental assessment/permitting process and a series of generic and project-specific mitigations.

The design of EEM programs for single exploration wells presents a challenge in that a single exploration well is drilled over a short period of 40 to 100 days. The well may be a 'dry hole' and also may leave little or no 'footprint.' In addition, there may be relatively little lead-time for an exploratory well relative to a production well. In contrast, development wells certainly contain hydrocarbons, drilling may go on for a few years, and the development may be producing for many years. The EEM strategies designed for oil field development and operation, or at least parts of them, may not be applicable to exploration wells, although their results may be relevant in scoping the potential effects of a single well vs. a multi-well scenario.

1.2. Boundaries of the Study

This study focused on single exploration wells that could be drilled anywhere on the East Coast of Canada using currently available technology at any depth during any season. It concerns EEM strategies that could be used to test impact predictions made in EAs for exploration drilling and to address concerns about exploration drilling.

Wells drilled to date off the East Cost of Canada are shown in Figures 1.1 and 1.2.

1.3. Issue Scoping

There were several possible approaches to this project: (1) workshop, or (2) focused consultations. An informal consultation approach was chosen for logistical reasons and because it was felt that people would speak more freely. In addition, there were too many potential issues and concerns, each requiring technical expertise, associated with exploration drilling to use a one or two workshop approach for this study. Some of these *a priori* issues included:

- Effects of the cuttings pile on the benthos,
- Effects of drilling mud in the benthic boundary layer on scallops,
- Comparison of effects of water based, oil based and synthetic based drilling mud,
- Effects of mud and cuttings on deep sea coral,
- Effects of the presence of the platform on birds,
- Effects of the exclusion zone on fisheries,
- Effects of produced water during well testing,
- Effects of underwater noise on marine mammals, and
- Effects of routine discharges.

The above list is not intended to be all-inclusive nor intended to imply that all of these issues are necessarily scientifically or technically based. This list does, however, reflect the concerns of a number of stakeholders.

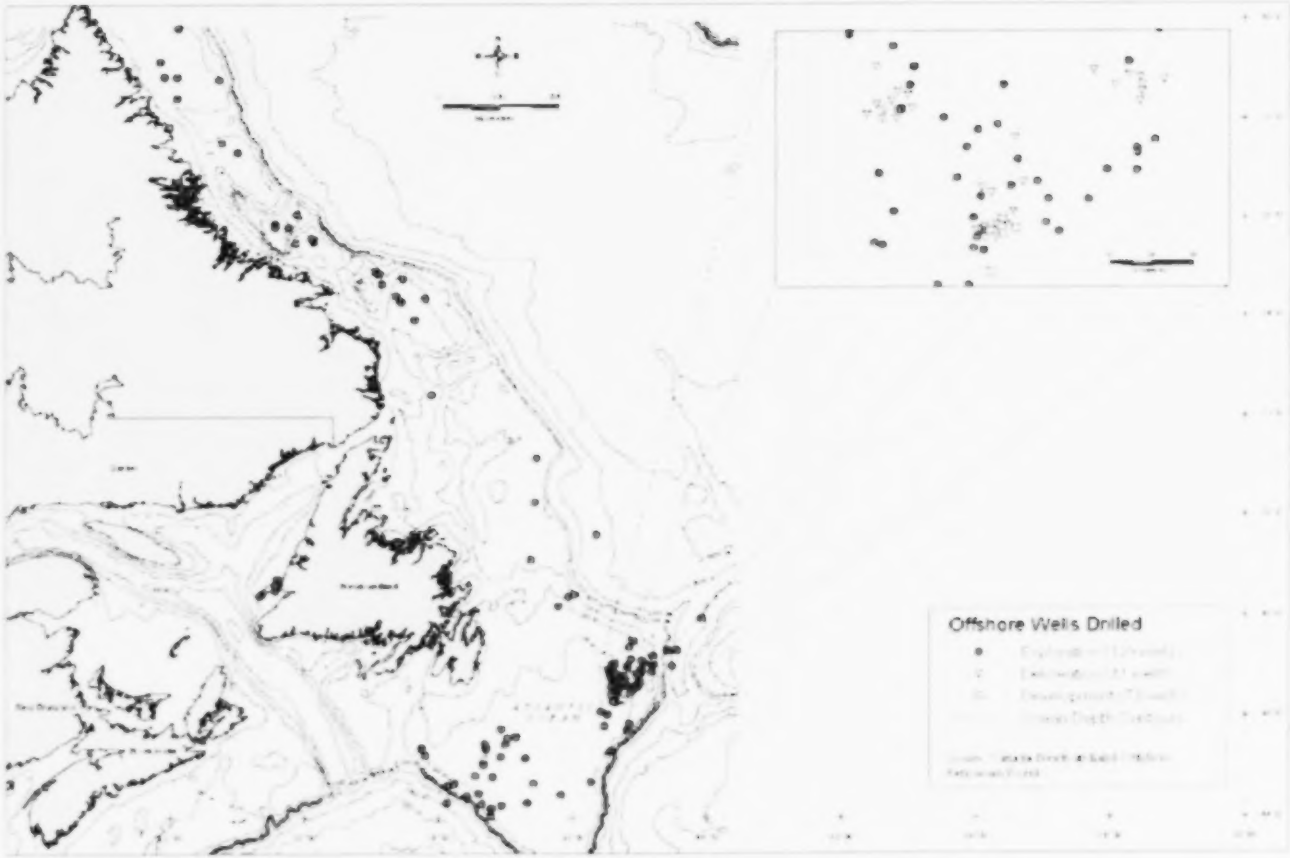

Figure 1.1. Offshore Wells Drilled in Newfoundland and Labrador Waters.

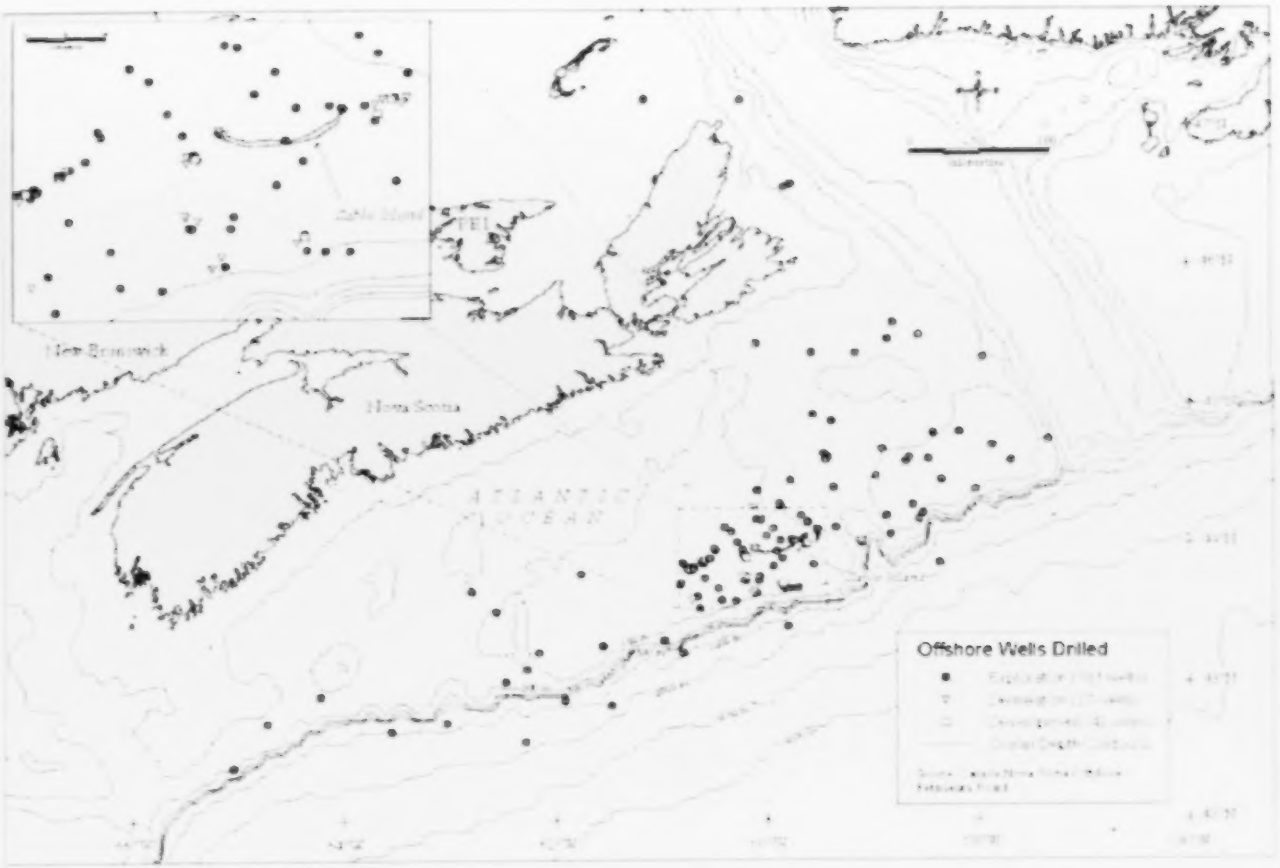

Figure 1.2. Offshore Wells Drilled in Nova Scotia Waters.

1.4. Development of an EEM Strategy for the East Coast

Once it has been determined that EEM is required, the methods used to monitor effects of exploration drilling on the East Coast should

- Address issues and concerns of stakeholders, regulators, scientists, NGOs, the oil and gas industry and interested parties,
- Test impact predictions made in EAs for exploration wells,
- Be effective in detecting effects,
- Be scientifically and statistically defensible,
- Be acceptable to the interested parties named above, and
- Be cost-effective.

In addition, EEM studies should determine:

1. whether or not there is an effect, and if not, consider if further studies should be discontinued. In some cases, in may be desirable to consider monitoring for reassurance purposes.

2. that if there is an effect, should studies be continued as mitigation measures are developed to reduce or eliminate the impact.

Some EEM studies may be applicable to all wells and some may be applicable to only certain types of wells. We used a scenario approach to determine the applicability of methods to specific kinds of wells and/or all wells. Type of drill rig, water depth, bottom type, currents, kinds of marine life present and predicted impacts, among other things, were considered in the application of methods to specific wells.

2.0 Background

2.1. Potential Issues and EEM Studies

One of the objectives of the study was to identify issues and potential EEM methods. Experience has shown that several key issues and concerns that may need to be addressed by EEM are common written and oral comments during public consultation for exploration wells or large production developments. Some of these are briefly reviewed below. Note that these are only a few recurrent issues and are not meant to be a comprehensive list. Additional issue scoping is contained in Section 3.0 based on informal local discussions with key informants.

2.1.1. Fish and Fisheries

Assessment of any potential impacts on fish and fisheries will continue to be of major importance for regulators and the oil and fishing industries with additional exploratory drilling off the East Coast.

Although valuable for assessing fish quality and marketability, chemical analyses of tissues are inadequate as a measure of fish health because

- Many chemicals do not accumulate in body tissues to any degree yet they can be quite damaging,
- Only a limited number of toxic chemicals in complex mixtures can be measured,
- The toxicity of many chemicals may not be due to the chemicals measured but by degradation products which are not readily measured, and
- There are few dose-response experimental studies linking body burdens of chemicals to effects; therefore, even knowledge about levels of chemicals in tissues can rarely be used to assess actual health effects (see Mathieu 2002, Appendix I).

Given the inadequacies of using chemical analyses as a measure of fish health and given that population level measures are both very expensive and unreliable for detecting change in the absence of major population level effects, there is increasing emphasis on use of biochemical and/or histopathological indicators of chemical stress to obtain an appreciation of the degree and severity of any potential health effects. These indicators are commonly referred to as bio-indicators or health effect indicators. Use of such indicators has the potential to identify adverse conditions in advance of responses at the population level and as such can provide early warning signals of any impending more severe problems.

It is equally important to stress that indicators are also a powerful tool for "disproving" as well as "proving" the deleterious effects of chemicals. For instance, perceptions or concerns about population level effects on fish stocks would have little scientific credibility in the absence of individual level effects.

Given regulatory and socio-economic concerns about potential impacts on fish and fisheries, a key component of the study was to "assess any potential impacts of exploratory drilling on the health and productivity of finfish and shellfish and recommend monitoring approaches and techniques if required".

2.1.2. Fisheries Exclusion Zone

The safety zone around a drill rig and its enforcement by standby vessels is frequently raised as a concern of the fishing industry in Nova Scotia. This issue was investigated during the collection of stakeholder views to assess the merits of monitoring the situation. It should be noted that the safety zone for a single exploratory well is much smaller than that for a production development.

2.1.3. Drilling Muds in the Benthic Boundary Layer

Individual fine particles in water based drill muds (WBM) settle slowly. However, fine particles interact with seawater and organic matter to form flocs (Munchenheim and Milligan 1996). This increases settling velocity and serves to retain the discharged material near the discharge point and hinders dispersal (Munchenheim and Milligan 1996). Material that is deposited can be re-suspended and transported (Neff et al. 1989). The accumulation of this material occurs within the benthic boundary layer, which is within a few metres of the sea bottom.

Accumulation of suspended drilling wastes in the benthic boundary layer has the potential to affect sensitive species such as scallops (Cranford and Gordon 1992; Cranford et al. 1999). Effects may include mortality at very high mud concentrations, negative growth and cessation of gonad growth. The benthic boundary layer transport model (referred to as the **bblt** model) has been used to model the fate of discharged WBM in the benthic boundary layer at exploration drilling sites. Some field testing of this model under ESRF auspices has been conducted by Hannah et al. (2003).

2.1.4. Benthos

Environmental effects monitoring programs in the offshore have commonly used benthic communities as indicators of impact, typically through use of community measures such as diversity indices and species richness, as well as patterns of occurrence and abundance of indicator species (e.g., capitellid polychaetes) (e.g., Kingston 1992; Olsgard and Gray 1995). Benthic community structure is also a key component of the Sediment Quality Triad approach to assessing impacts of industrial activities on aquatic ecosystems (e.g., Chapman et al. 1991; Green and Montagna 1996; Carr et al. 1996a; Borgmann et al. 2001), currently used in offshore monitoring programs for the Sable Offshore Energy Project, and Terra Nova on the Grand Banks.

2.1.5. Cuttings Pile

Cuttings and any remaining adherent mud are normally discharged subsurface from the drilling rig. The heavy particles settle near the discharge site and may form a pile on the bottom. An examination of three exploration well sites drilled with water-based muds in the Hibernia field revealed only slight accumulations of drilling materials (NORDCO 1983). However, accumulation depends on depth, water currents and frequency of storm surges. The concern is with smothering of the local benthos and potential loss of a small amount of fish habitat.

2.1.6. Deep Sea Corals

Through interviews with fishermen, examination of museum collections, discussion with researchers and a literature review, Breeze et al. (1997) mapped the distribution of deep sea corals on the Scotian

Shelf and Georges Bank. The corals are distributed in canyons along the edge of the continental shelf and in the deep channels between fishing banks. These long-lived, slow-growing sessile filter feeders are extremely sensitive to changes in current, suspended sediment and temperature, and appear to be good bio-indicators of environmental deterioration. Fishermen have reported changes in coral abundance in several areas, largely due to the impact of mobile fishing gear. There is a concern that settled drilling waste could affect these corals.

2.1.7. Birds

There is a concern that night-flying birds, especially petrels, are attracted to lighted rigs. The birds become disoriented and land on the rig. Procedures have been developed for dealing with these birds and appear to work well, however, no formal monitoring results are available to date. There is some concern that birds could be burned in flares or fly into the structure. There is also a concern that birds could be attracted to the structure and be subject to predation or land on sheens on the water. The ESRF has issued RFPs aimed at studying these issues.

2.1.8. Scientific Credibility of Potential EEM Programs

EEM programs that are developed must be scientifically credible and acceptable to stakeholders. At the same time, the parameters to be measured need to be appropriate for measurement at reasonable cost. Scientific credibility can be assured by using state-of the-art techniques and by involving statisticians to review final designs. Studies should include appropriate provisions for analyses to determine optimum sample size and allocation of resources to give the best possible chance of detecting effects and *a posteri* power analysis to determine the power of the test to detect change. The study design should include provisions for modification based on the results of statistical power tests.

Scientific credibility would be of little value if stakeholders were not convinced that the results were valid. Thus, the programs must address their concerns and produce results that are credible to both scientists and the concerned public.

2.2. Typical Exploratory Drilling

Exploratory drilling on the East Coast is normally examined under an environmental assessment (EA). Typical issues addressed include:

- Noise and disturbance associated with support activities and drilling (e.g., supply vessels, helicopters)
- Effluents and emissions of the drill rig (sanitary, grey water, mud and cuttings, etc.)
- Accidental events
- Well abandonment activities

Drilling and testing the typical exploration well on the shelf may take about 40 days for drilling and an additional 20 days for testing if hydrocarbons are found.

Normally if there any concerns with the exploratory drilling, they tend to revolve around the disposition of mud and cuttings on the sea floor, accidental events such as spills or blowouts, and disturbance of marine birds and mammals, if the area is deemed to be an important area for these species. To date, all EAs for drilling have predicted that any environmental effects will be not significant with the possible exception of a major oil blowout (e.g., Petro-Canada 1996; Husky 2000, 2002, 2003a).

Compliance monitoring and EEM (in the case of development and production scenarios) focuses on effluents and emissions. Monitoring of spills is considered separately from compliance monitoring or routine EEM.

The following sections provide a brief description of typical exploratory drilling equipment, procedures and activities. Emphasis is on those aspects relevant to EEM.

2.2.1. Drill Rigs

Worldwide, there is a wide variety of drilling rig types in common use. Typically the offshore drill rig houses the drilling equipment, working and living quarters and is serviced by helicopters and supply vessels. To date, the most common drill rig in use on the Grand Banks has been the semi-submersible (e.g., the *Glomar Grand Banks*). Semi-submersibles are normally anchored but some can be dynamically positioned without anchors. Hibernia is the exception as drilling is conducted from the concrete, gravity base structure (GBS) that also houses the production facilities. In Nova Scotia, 'jack-up', bottom-founded rigs have been typical but as drilling moves into deeper water there is a trend toward semi-submersibles or drill ships.

There may be some minor differences between and within rig types in terms of capabilities, treatment facilities, effluent discharge depths, and so forth but, for the most part, each rig is fairly 'typical' in terms of characteristics, volumes and types of discharges. All must conform to the *Offshore Waste Treatment Guidelines* (*OWTG*) (NEB et al. 2002). Rig types do differ in terms of the noise emitted with dynamically positioned drill ships being the noisiest and the 'jack-up' being the quietest.

Drill mud handling is an important duty of the rig (see below). Other equipment and material includes casings, cement to bond the casings, risers and blowout preventers (BOP).

2.2.2. Drill Muds

Drilling muds are needed to convey the drill cuttings out of the hole and to keep formation fluids from entering the well. During the drilling of the top hole sections, the riser is not in place and drilling mud and cuttings (or sediments) from the top part of the hole are discharged from the hole to the seabed. [Drill muds and cuttings are no longer a potential issue with Hibernia, as that production facility will be re-injecting their cuttings. This approach is not presently feasible for the single offshore exploratory wells using existing drilling units on the East Coast.]

All exploratory drilling on the East Coast is conducted using either water-based drilling muds (WBM) or synthetic-based muds (SBM). It is debatable which type is more or less 'environmentally friendly.' For example, it can be argued that WBM is better because it is mostly water and cannot form a sheen on the surface whereas SBM may form one under certain conditions. On the other hand, SBM generally stays

closer to the well site and does not disperse as widely as WBM. All drilling fluids should be handled and treated in accordance with C-NOPB and C-NSOPB policies and the *OWTG*.

After installation of the initial casing strings, the riser provides a conduit from the seabed to the rig that takes the drilling mud and cuttings back to the surface mud system. Once on board the rig, the drill cuttings are removed from the mud in successive separation stages and discharged. Some mud remains with the discharged cuttings. At several stages during drilling and at the end of the drilling process, WBM is discharged.

The main component of WBM is either fresh water or seawater. The primary WBM additives include bentonite (clay) and/or barite. Other chemicals such as potassium chloride, caustic soda, soda ash, viscosifiers, filtration-control additives and shale inhibitors are added to control mud properties. Low toxicity chemicals are used for the water-based drilling mud to reduce the effect on the environment.

From the top down, a typical exploratory hole involves a conductor, surface and progressively smaller casings, perhaps as many as five. Mud and cuttings cannot be returned to the rig until the surface casing is in place and thus mud and cuttings from the conductor and surface parts of the hole are initially discharged directly to the seabed. Once the surface casing is complete, the risers are installed, and the mud and cuttings are returned to the rig through a closed system for recycling and cleaning before cuttings and any residual mud are discharged. The discharge is treated and exits via shute to just below the water's surface subject to Board approval. The mud and cuttings are dispersed in the water column and settle on the sea floor with the heavier particles near the hole and the fines at increasing distances from the rig. [One industry respondent interviewed during the course of the present study offered the following observation. "Muds/cuttings emanating from drill rigs located near Sable Island have been observed to form into a long, tendril-like plume on the ocean surface extending several kilometres from the source, presumably in the predominant direction of the surface current."]

The conductor setting depth is site-specific and subject to Board approval but a typical depth on the Grand Banks might be about 250-m as measured from the rotary table (i.e., MD). The typical surface casing setting depths may be on the order of 1,200-m MD. Estimated volumes of water-based mud and cuttings discharges associated with initial casings for a typical Grand Banks (White Rose area) well are shown in Table 2.1. It should be noted that the muds/cuttings from the production casing phase are passed through the solids control system that consists of shale shakers and centrifuges.

Drilling muds and cuttings, and their potential effects were discussed in detail in the White Rose Comprehensive Study (Husky 2000) and Supplement (Husky 2001a). Modeling of the fate of drill mud and cuttings discharges was conducted for the White Rose EA. The White Rose EA analyzed the effects of the discharge of drilling wastes from development drilling of 25 wells using SBM at multi-well drilling sites. As such, the White Rose scenario can be considered a 'much worse case' than the exploratory drilling of one individual well. The White Rose development drilling was deemed to create no significant effect on fish and fish habitat, the fishery, seabirds, marine mammals, or sea turtles. Additional relevant documents not available during the White Rose EA include MMS (2000); CAPP (2001a,b), NEB et al. (2002), the White Rose baseline studies (Husky 2001b, 2003b), and Husky exploratory drilling EAs (Husky 2002, 2003a) all of which discuss the discharge of mud and cuttings and associated effects. These recent reports have further confirmed the conclusions of the White Rose work that routine drilling, particularly small scale drilling, has no significant effect on the marine

environment of the Grand Banks. The salient points are briefly summarized in the two following sections and the results of baseline and monitoring studies related to offshore drilling programs are presented in Sections 2.5 and 3.0.

Table 2.1. Typical Mud Components and Cuttings Discharge Volume for a Grand Banks Exploration Well.

	Unit	Casing Strings			
		Conductor	Surface	Production	
Hole Section	inch	36	16	12 1/4	Notes:
DF System		Gel/SW	Gel/SW	WBM	1. Three scenarios were taken into account. The 12 ¼" hole section varies in depth with each scenario.
Depth (See Note 4)	Meter (brt)	220	1200	3600	
Volume Usage	bbl	897	4199	5246	
Wash Out	%	50%	30%	10%	
Products					2. 36" and 16" hole sections–Near seabed discharge.
Barite	MT		58	115	
Bentonite	MT	16	65		3. WBM used for complete well.
Calcium Carbonate	kg				
Caustic	kg	116	482	138	4. All depths are measured below rotary table (brt). The rotary table is 145-m above the seafloor.
Fluid Loss Agent	kg			2385	
Inhibitor	kg			4769	
Fluid Loss Agent	kg			9538	
Potassium Chloride	kg			100153	
Lime	kg	116	482		
Glycol Inhibitor	L			25024	
Soda Ash	kg	116	482	238	
Viscosifier	kg			3577	
Biocide	L			72	
Drilled Cuttings	kg	192032	429562	521786	
Volume of Cuttings	m^3	74	165	201	

Source: Husky (2003a).

2.2.2.1. Water-Based Muds

At present, and for the near future, most exploratory wells at least on the East Coast, will be drilled with WBM unless unexpected, difficult or highly deviated conditions are encountered and then, with the approval of the Board, they may use SBM (discussed in a following section). Composition of one typical WBM formulation for an exploratory program is shown in Table 2.1.

The following points are relevant to the discharge of WBM and cuttings.

- WBM are essentially non-toxic. The main component of WBM is seawater and the primary additives are bentonite (clay), barite and potassium chloride. Much previous literature (e.g., the North Sea) on the effects of mud/cuttings deals with field where oil-based muds (OBM) were used for a number of years. The OBM literature is not very relevant to WBM or SBM usage.
- Chemicals such as caustic soda, soda ash, viscosifiers, and shale inhibitors are added to control mud properties. All constituents are normally screened using the *Offshore Chemical Selection Guidelines* (NEB et al. 1999).

- Discharge of WBM and associated cuttings is regulated by the C-NOPB and C-NSOPB. Spent and excess WBM and cuttings can be discharged without treatment (NEB et al. 2002).
- The discharge of WBM may increase metals in sediments such as barium, arsenic, cadmium, copper, mercury, lead, and zinc, generally within 250 to 500-m of the drill site but occasionally farther (usually zinc and sometimes chromium) depending upon mud volumes and environmental conditions. However, these metals are not in a bioavailable form and few if any biological effects have been associated with these increases in metals from drill rig discharges (CAPP 2001b).
- The primary effect of WBM appears to be smothering of benthos in a small area near the hole. The exact area of effect cannot be predicted because animals' reactions will range from simply avoiding the immediate area of deposition to direct mortality of sessile organisms. Nonetheless, the White Rose EA indicated a worst-case scenario of an area of less than 1-km^2 around each well would have a depth sufficient to result in some smothering (Husky 2000, 2001a). The exploratory drilling for one well would be well below the worst-case scenario used for the White Rose EA. The benthos can be expected to recover in anywhere from several months to several years (and most likely within one year) after the drilling ceased, based upon the published literature (reviewed in Husky 2000, 2001a; MMS 2000; CAPP 2001b). Actual monitoring data from other operators indicate that the actual area of smothering appears to be much less than predicted (Fechhelm et al. 2001; Marathon, unpubl. data).

2.2.2.2. Synthetic-based Muds

Synthetic-based muds (SBM) are not used in the typical exploratory program unless difficult or unexpected hole or reservoir conditions are encountered. Synthetic muds were developed to replace oil-based muds which were considered toxic to varying degrees and which appeared responsible for the longevity of cuttings piles. In general, SBM is essentially non-toxic, has the potential to biodegrade relatively rapidly, and less mud is required than for WBM for the same distance drilled. SBM tend to 'clump' cuttings together more than WBM thus SBM cuttings tend to disperse less and fall closer to the rig.

The following points concerning SBM are relevant to an exploration drilling program EA on the East Coast.

- In other jurisdictions, biological effects have been attributed to smothering under the patches of mud/cuttings from physical and/or chemical (i.e., anoxia caused by rapid biodegradation) conditions (e.g., EPA 2000).
- In Nova Scotia, SBMs have been handled in a number of ways including shipping to shore, injection, and discharge.
- In the deepwater (500+-m), Gulf of Mexico, organic enrichment with attendant increases in biota, including fishes and crabs, has been reported after a two year multi-well drilling program (Fechhelm et al. 2001). No large cuttings piles were observed by ROV during that study.

- Biological effects are not normally found beyond 250-500-m from the drilling platform (Husky 2000, 2001a, 2002, 2003a; MMS 2000; CAPP 2001b; C-NOPB 2002). The Husky EAs (White Rose, Jeanne d'Arc Basin, and South Whale Basin) concluded a total area of impact of less than 1-km^2 from multi-well drilling based upon a modeling exercise and published literature. It can reasonably be expected that a single exploratory well would affect a much smaller area.
- In the event that SBM must be used, the cuttings are treated prior to discharge. All discharges are subject to approval by the Boards and discharge of whole SBM is not permitted.

2.2.2.3. Mitigation

Mitigation measures for the drilling include the selection of non-toxic or low toxicity chemicals and muds and treating any oil-contaminated cuttings to meet the *OWTG*. Hibernia now re-injects cuttings as a mitigation for production (not exploration) drilling. However, the Hibernia situation is atypical for the East Coast being a very large development that does all its drilling from a centrally located gravity-base structure.

2.2.3. Discharge of Other Fluids and Solids

Other fluids associated with the drilling include cement slurry and BOP fluid. Mitigations include careful selection and use of chemicals in order to minimize any potential toxic effects.

Based on experience with previous exploratory wells, approximately 33-t (26.4-m^3) of excess cement may be released to the marine environment per well (Husky 2000), and may smother or displace some benthos locally. If the cement remains in a pile, it will act as an artificial reef, be colonized by epifaunal animals and attract fish. The effects (either negative or positive) of the cement on benthos are likely negligible.

Blowout preventer (BOP) fluid is used in the blowout preventer stacks during drilling. The fluids are normally glycol-water mixes. Periodic testing of the blowout preventer is required by regulation. Approximately 1-m^3 of the fluid is released per test. Periodic releases of this small amount of glycol likely have a negligible effect on marine biota.

In some cases, small amounts of produced water may be released during testing, if hydrocarbons are discovered. Sometimes this is released but it may also be burned, or if present only in small quantities, disposed on shore.

Concerns about birds and mammals are normally related to accidental events (beyond our mandate here) and/or the perceived importance of a particular area. For example, bird (particularly petrels) attraction to rigs was an issue during both Terra Nova and White Rose hearings because the areas are known to support large numbers of petrels, which may be particularly sensitive to this type of disturbance. Similarly, noise of drilling and support activities may be an issue near known concentrations of whales (e.g., bottlenose whale population in the Gully, offshore Nova Scotia).

2.3. Exploratory Drilling – Cumulative Effects

On the Grand Banks to date, there have been over 233 exploration, delineation, and production wells (C-NOPB data) (see Figure 1.1). The Canadian Association of Petroleum Producers (CAPP) has predicted that there will be between one and four drill rigs per year operating on the Grand Banks over the next 10 years (CAPP 1999). CAPP's scenario for a moderate level of activity predicts two rigs drilling exploration, delineation and production wells on the Grand Banks over the next ten years.

In Nova Scotia waters, over 170 wells have been drilled to date (C-NSOPB data) (see Figure 1.2). It is likely that there will be at least one or two rigs operating in Nova Scotia waters over the next 10 years.

2.4. Regulatory Regime

Different jurisdictions have different approaches to environmental protection for offshore drilling which range from no EEM to custom programs. Some of these approaches are briefly described below.

2.4.1. International

2.4.1.1. Gulf of Mexico

There are have been many thousands of exploration, delineation and production wells drilled in the Gulf of Mexico, mostly in relatively shallow water on the shelf. The present trend is to drill in the deeper water of the slope and basin of the Gulf.

There have been extensive studies of the biota in the Gulf under many auspices and there have been numerous research studies conducted for specific developments. While there are some specific EEM programs such as the Flower Garden Banks that have been monitored every year since the 1980's and some deepwater (1,000-m) research studies of two exploration and two production platforms using sidescan profiling and biological mapping, there are no EEM requirements for single exploratory wells (G. Boland, MMS, pers. comm.).

Because there is a large body of evidence for the Gulf that effects, even in deepwater, of exploratory drilling, occur within 1,000-m of the rig, emphasis is on a type of zoning to avoid sensitive areas and compliance monitoring to EPA effluent guidelines once the project goes ahead. Sensitive areas include topographic features that may contain coral reefs or other hard substrates that constitute limiting habitat in the predominately soft-bottomed Gulf. Buffer zone widths ranging from 1,000-m to four miles may be used as a protective measure. Thus, zoning and mitigation techniques are used for oil and gas exploratory drilling in the Gulf as opposed to a case-by-case EEM program.

2.4.1.2. Alaska

Regulatory requirements concerning EEM in Alaskan waters can be complex because a number of regulators (e.g., federal such as National Marine Fisheries Service, US Biological Service or EPA; state such as Alaska Fish and Game and Division of Oil and Gas; local such as North Slope Boroughs, and others) may take an interest in a particular project depending upon the location, water depth, time of year and type of drill rig, and so forth. The primary line of defense is the permitting process and compliance monitoring; the ultimate goal for effluents is 'zero discharge' offshore.

There are no 'hard and fast' rules for EEM but it is very likely that marine mammals (e.g., whale migrations and possibly ringed seals in summer, and seals in winter), and noise would have to be monitored for an offshore exploratory well drilled in Alaskan waters (B. Wilson, LGL, pers. comm.). However, strictly speaking, it could be argued that this type of monitoring can be considered mitigation as opposed to EEM because precautionary shutdowns may occur because of the monitoring.

2.4.1.3. Other

Very few, if any, jurisdictions have EEM requirements for exploratory drilling. For example, the Canadian oil company Nexen operates offshore exploration internationally in West Africa, Brazil (with Petrobras), Indonesia, Australia, and the Gulf of Mexico. Of these areas, Australia is the only jurisdiction that has some requirement for EEM depending on location and timing of drilling (W. Robson, Nexen, pers. comm.). On the other hand, there may be certain circumstances where a company might voluntarily conduct 'before' and 'after' surveys in order to address liability issues (W. Robson, pers. comm.).

2.4.2. Canadian

At the time of writing the first draft of this document there were no specific EEM requirements for drilling exploratory wells offshore on the East Coast. However, it should be noted that as of 30 October 2003, the revised *Canadian Environmental Assessment Act* states that some form of 'follow-up' is required for projects that have undergone any *CEAA* process including screening. It remains to be seen if this is an actual EEM 'requirement' in all cases. In the Canadian Arctic, there may be requirements to conduct marine mammal monitoring depending upon location and season. For the most part, environmental protection is achieved through the environmental assessment/permitting process and a series of generic and project-specific mitigations.

On the East Coast, the C-NOPB and C-NSOPB require that effluents and discharges be monitored (i.e., compliance monitoring) according to the *OWTG* (NEB et al. 2002). Effluents and discharges that fall under these guidelines include:

1. Air emissions
2. Produced water
3. Drilling muds
4. Drill cuttings
5. Well treatment fluids
6. Storage displacement water
7. Bilge and ballast water
8. Deck drainage
9. Cooling water
10. Produced sand
11. Desalinization brine
12. Fire water
13. Sewage and galley waste

14. Monoethylene glycol
15. Naturally occurring radioactive materials (NORM)
16. Other wastes (solid waste, residues, etc.)

Of these, in the case of exploratory drilling, items 2 to 4, and 7 and 8 would be routinely monitored. Other items may be specified on a case-by-case basis.

2.5. Review of Effects

A detailed review of effects reported from various relevant research and EEM studies worldwide is contained in Mathieu 2002 (Appendix I). A brief summary is provided below.

2.5.1. Toxicity Potential of Drilling Fluids and Cuttings

Drilling fluids (muds) and cuttings have potential for both lethal and sublethal effects on marine organisms (mostly sedentary ones) through introduction of contaminants from chemical additives or from the downhole geology or by physical smothering, mostly of sedentary benthic organisms. Most offshore drilling worldwide is now conducted using water-based or synthetic-based muds; these fluids range from non-toxic to low toxicity compared to previous fluids that utilized diesel oil as the base. Literature on the topic must be treated with caution because effects from older wells that used oil-based mud must be separated from the newer ones. It also should be noted that care must be taken in interpreting benthic data near offshore platforms because the reef effects caused by the presence of the platform may be equal to, or even greater than, those caused by contaminants (see Montagna et al. 2002).

As discussed previously, it is debatable as to the level of environmental effects of WBM versus SBM. In a typical offshore situation, WBM tends to disperse more widely whereas SBM tends to clump together closer to the well site. Both contain ground barite and/or bentonite, dispersants, viscosifiers, fluid control agents, and corrosion inhibitors. Most additives are practically non-toxic as measured by 96-h acute toxicity testing (e.g., concentrations >10,000-ppm with most ≥100,000-ppm), and most drilling wastes can be considered only slightly toxic (1,000-10,000-ppm) or practically non-toxic (>10,000-ppm) (GESAMP 1993). A variety of SBMs have passed the US criteria for toxicity from suspended particles to mysid shrimp (LC50's >30,000-mg/L) and an SBM used offshore Newfoundland (a synthetic isoalkane, IA-35) has been tested and found to have a very low toxicity (see Neff et al. 2000; Payne et al. 2001a,b). Synthetic fluids can be categorized as synthetic alkanes, ethers, esters, or olefins; the most rapidly degrading ones can create localized anaerobic conditions in the underlying sediments (EPA 2000). Chemicals used off the East Coast of Canada are screened and selected for lowest toxicities (see NEB et al. 1999).

Smothering from mud and cuttings discharge from a single exploratory well is likely confined to a very small area and should not be an issue, although benthic communities may be affected by physical alteration of the sediments (e.g., Cantelmo et al. 1979). However, concern has been expressed that barite or bentonite can become suspended in the benthic boundary layer (Muschenheim and Milligan 1996) and may affect scallop growth (Cranford et al. 1999).

Barite (barium sulfate) is an insoluble, relatively low toxicity form of barium which in ionic form is quite toxic. Pathological effects of barite have been reported for bivalves (Cranford et al. 1999), shrimp (Conklin et al. 1980), and flounder (J. Payne, DFO, pers. comm.). WBM and SBM are generally of low toxicity but that there are potential effects from mud and cuttings other than changes to benthic community structure that should be examined for an EEM program, for example, effects on flatfish as determined by mixed function oxygenase (MFO) and histopathology.

2.5.2. Biological Effects: Single or Low Number of Wells

Results of an extensive literature review of developments involving one or few exploratory or production wells are in the tables contained within Appendix II.

The review considered worldwide results from 18 locations using WBM with water depths ranging from eight to 410-m and 17 locations using SBM (a few with LTMO) with water depths ranging from 30-m to 565-m. In addition, seven locations from the East Coast with depths ranging from 20 to 90-m were examined; some used WBM, SBM or low toxicity mineral oil (LTMO).

In summary, effects as measured by various biological indices on sediment communities generally ranged somewhat farther using WBM than SBM but in most cases were within a few to 500-m of the well or set of wells and most commonly within a 200-m radius.

2.5.3. Perspective on Exploratory Drilling Versus Other Industrial Activities

It is useful to place the risk to the environment and the scale of effects created by exploratory drilling compared to other industrial activities such as commercial fishing and shipping. To date, exploratory drilling, in so far as can be determined, has had a relatively mild effect on the marine environment of the East Coast. Monitoring of large-scale offshore oil developments, involving multiple wells (e.g., Hibernia, Terra Nova, and White Rose) has failed to discover any significant impacts on those elements of the ecosystem that have been measured. It should be noted that care should be taken in extrapolating effects from other oil fields such as the Gulf of Mexico or the North Sea because those areas contain many thousands of producing oil wells that were drilled over a number of years. Furthermore, while there has been a gas blowout off Nova Scotia, there have been no oil blowouts off Newfoundland. In contrast, chronic illegal release of oily water by disreputable ship captains on freighters and tankers continues to result in the mortality of thousands of seabirds off the south coast of Newfoundland (W. Turpin, CWS, pers. comm.).

The fishing industry has caused major significant effects off the East Coast (e.g., the failure of the Atlantic cod fishery, and others). The scale of effects created by routine fishing industry activities is potentially much greater than those from routine petroleum exploration activities. For example, the combined biological effects of petroleum activities in the North Sea affected an area of about 106-km^2 in 1989 whereas other UK waters such as the Irish Sea (2-3,000-km^2 in area) are completely trawled over 2.5 times per year (GESAMP 1993). The effects on benthic habitat of fishing dredges and trawls are well recognized (Veale et al. 2000; Watling et al. 2001; Wassenburg et al. 2002, and others). The National Academy of Science (1983) noted in their review of drilling discharges that while a single well may deposit 442-m^3 of cuttings, a single fishing vessel, dredging for surf clams, cuts an average swath about 1.5-m wide and 46-cm deep, potentially impacting 4,300-m^3 of sediment per day.

The attempt of the above comparisons is intended to place a perspective or scale on the drilling issues under discussion and not disparage the fishing or any other industry.

2.5.4. Biological Monitoring State of the Art

Environmental quality is ultimately biological in nature and over the past number of years there has been increasing emphasis on the use of biological techniques in monitoring programs in order to supplement more traditional chemical approaches, which were commonly used alone. There are a number of reasons for this shift in emphasis towards biological monitoring. For instance, reliance on chemical analysis alone presupposes that the contaminants of concern are known and dose-response relationships have been established for effects on various ecosystem components. This is rarely the case for any chemical or any species. Furthermore, only representative contaminants can be measured, and chemical analyses cannot consider factors of biological significance such as the combined effects of contaminants, their degradation products and their interaction with environmental factors. The International Commission for the Exploration of the Seas (ICES) has recommended biological monitoring techniques for the marine environment under the framework of the Olso and Paris Commissions (Table 2.2). The list of techniques is not unlike those which are being used already in many "informal" as well as more formal monitoring and assessment programs (e.g., studies by the National Oceanic and Atmospheric Administration in the United States).

Table 2.2. Biological Effects Techniques for Monitoring as Recommended by the Oslo and Paris Commissions (Stagg 1998).

Type of monitoring	Purpose	Monitoring methods
General biological effects monitoring	• Monitor general quality status	• *Early warning indicators:* Cytochrome P-450 1A, lysosomal stability, liver histopathology (e.g., preneoplastic changes), reproduction in viviparous blenny • *Indicators of long-term change:* External fish diseases, benthos community structure studies, the occurrence of liver nodules
	• Identify known or suspected areas of impact	• *Bioassays:* Sediment, Pore water and water column • *Biomarkers:* Cytochrome P-450 1A (EROD), lysosomal stability, liver pathology/nodules in caged or sedentary organisms • *Population/community responses:* External fish diseases, reproduction in viviparous blenny, benthos community structure studies, liver histopathology
Contaminant-specific effects monitoring	• Effects of PAHs	• PAHs in sediment, PAH metabolites in bile, EROD in liver, DNA adducts in liver, liver pathology
	• Effects of Hg, Cd, Pb	• Metals in sediment and liver, metallothionein in liver, ALA-D in blood, antioxidant defenses in liver
	• Effects of TBT	• TBT in flesh, imposex/intersex in gastropods or shell thickening in *Crassostrea*

Analysis of benthic community structure or benthic community structure in combination with sedimentary microtoxicity tests is recognised, including by ICES, as a valuable approach for assessing impacts on sediment habitat. Analysis of benthic community structure has also been one of the most widely used techniques for assessing sediment habitat impact around petroleum exploration and development sites. This is the case for developments in the North Sea and the Gulf of Mexico and more recently in Canada and Australia (Mathieu 2002, Appendix I). Studies indicate that any potential for significant impacts on sediment habitat around single exploratory or development wells through use of synthetic, or water base muds should generally be confined to within a few to 200-m of rig sites, if at all, (with impact zones being possibly somewhat shifted away from the immediate area of rig sites in deeper waters with fast currents). Impacts associated with multiple wells can also fall within the <200-m range. Also, benthic impacts associated with petroleum development are indicated to be quite small in comparison with other impacts such as those produced by fishing activities.

Considerable emphasis has been placed on studies of sediment communities around relevant well sites and the scale of impacts is fairly well known to be quite limited or negligible. However, there is a general lack of data on effects on fish and shellfish or other component which may be at some risk. Since population level effects in species such as fish would be both highly expensive to investigate and difficult to detect in the absence of major impacts, there is increasing emphasis on use of biochemical and histopathological indicators of chemical stress to obtain an appreciation of the degree and severity of any potentially impending problems in the marine environment. These indicators are commonly referred to as early warning or health effect bioindicators. Relevant indicators for monitoring effects in fish and shellfish such as induction of MFO enzymes and histopathology are noted in the list of techniques recommended by the Oslo and Paris Commissions (see Mathieu 2002, Appendix I).

Assessment of any potential impacts on fish and fisheries can be of considerable socioeconomic importance for regulators and the oil and fishing industries alike; bioindicators can provide a powerful tool for assessing if effects are occurring and if so, whether they might be of regulatory or socio-economic importance. For instance, perceptions/concerns about population level effects would have little scientific credibility in the absence of continuing evidence for individual level effects some distance from rig sites.

Laboratory studies indicate a potential for localised effects on fish and shellfish around petroleum development sites (e.g., Cranford et al. 2001 and references therein). Studies in the UK sector of the North Sea have demonstrated induction of MFO enzymes in fish around some platforms (Davies et al. 1984; Stagg et al. 1995). Histopathological lesions have also been found in finfish (Gallaway et al. 1981; Grizzle 1986) and shrimp (Wilson-Ormond et al. 1994) around some production platforms in the Gulf of Mexico. Recognising that most of the biological monitoring programs carried out to date in association with oil development have primarily emphasized investigations on impacts on sediment habitat, and given the potential for effects on fish and other pelagic organisms around rig sites, studies have recently been carried out under the auspices of ICES around a development site in the North Sea. These studies have confirmed a potential for effects on fish and shellfish around platforms (ICES Workshop 2002).

It is noted that the bioindicator studies carried out to date with fish and shellfish have been in association with production sites and the effects observed may primarily be linked to produced water. However, chronic effects associated with other potential contaminants including these found in drilling fluids cannot be discounted. As for impacts on benthic communities, any potential for impacts on fish around

exploratory sites and especially these involving single wells some distance apart would seem to be quite low. It is of interest in this regard that Terra Nova has carried out fish health studies on a commercially important flatfish (American plaice) around their site in advance of development (JWE Ltd. 1998). No differences were noted in the bioindicators studied between their predevelopment site, where a number of wells have been drilled, and the reference site. Similar observations on bioindicators of fish health have also been made with respect to the predevelopment site at White Rose where a number of wells have been drilled (JWE Ltd. 2000). These field results are consistent with observations by Payne et al. (1995) who found little evidence for health effects in flounder chronically exposed to levels of drilling fluids (aliphatic hydrocarbon based) similar to those commonly found beyond 200-m or so from rig sites. The laboratory studies of Cranford et al. (1999) with scallops and Conklin et al. (1980) with shrimp also indicate that any significant potential for localised effects should be more or less in association with deposits from multiple, not single wells. However, in the absence of evidence and with due regard for unknown chronic toxicity potentials, effects on fish, shellfish or other ecosystem components could be greater than those on sediment communities. It is also recognised that it is often important to provide assurance that effects are not occurring in some species. This could apply for instance to commercially important fish, "species at risk" or other high profile species.

2.5.5. General Approach to Biological Effects Monitoring Around Exploratory Wells

Organisms (fish, shellfish, etc.) which might be of importance for assessment would depend on the exploratory site. Candidate indices for monitoring effects in the marine environment have been recommended by the Oslo and Paris Commissions (see Mathieu 2002, Appendix I). These include well known indices such as benthic community structure, sediment bioassays, MFO enzymes, and histopathology. With respect to determination of health effects in individual organisms, concepts such as growth and histopathology can be applied to a large variety of animals in addition to fish. However, the nature of environmental effects monitoring, precludes being too prescriptive since new techniques are always evolving or novel environmental observations may be made requiring a change in approach. For instance, specific cytochemical changes in bivalves (peroxisomal proliferation) are evolving as a novel technique for assessing pathological effects produced by hydrocarbons and other organic chemicals in bivalves. Similarly, depending on purpose, caged or resident organisms could be studied. For instance, concerns about potential for effects on general environmental quality could be addressed in part by caging selected animals near discharge sites. However, such an approach could greatly exaggerate exposure conditions and produce highly misleading results should the question be related to whether resident organisms such as commercial fish species are being affected to any degree around rig sites.

3.0 Environmental Effects Monitoring Programs for Production

The following sections provide more detailed reviews of EEM programs conducted on the East Coast for offshore oil and gas production developments. The most detail has been provided for the Sable Offshore Energy Project (SOEP) which can be considered a 'case study' (see below).

This project was selected as the primary case study because at the time of this writing more detail was available for SOEP whereas mostly summary material was available for the other East Coast projects. In general, study designs and results for all of the projects have been similar, with the exception of a number of minor differences.

Most EEM data collected off the East Coast to date has been for monitoring large production developments. As such, the data should be treated with the cautions that there are other potential environmental stressors at work other than drilling activities. Other stressors could include glory hole excavation, produced water discharge, and so forth. Nonetheless, offshore drilling for exploration wells entails essentially the same equipment, muds and cuttings and activities as drilling for delineation, injection, or production wells. Thus, both baseline and EEM data collected for such projects as Hibernia or SOEP are definitely relevant to EEM for exploratory drilling.

3.1. The Scotian Shelf

There have been three environmental effects monitoring programs on the Scotian Shelf, two for production developments and one for an exploratory well. To date, monitoring for each project has focused on the valued ecosystem components (VECs) identified in the environmental impact statements (EIS) prepared by the proponents. VEC selection is individualized for each proposed project, but the broad potential impact categories are quite similar, and these broad categories are used as the basis for monitoring program design.

Production EEM programs on the Scotian shelf were for the Sable Offshore Energy Project (SOEP) and Cohasset/Panuke (CoPan). Common monitoring elements included effects on local fishing communities, effects on bottom communities through sediment transport, and effects to seabird and marine mammals.

3.1.1. Sable Offshore Energy Project

Sable Offshore Energy Inc. (SOEI), operators of SOEP, divided their effects monitoring programs into two components, (1) near shore environments and (2) offshore environments. The near shore component focused on installing the pipeline to shore, so only the offshore components potentially relevant to drilling activities are considered here.

Offshore monitoring included VECs and associated concerns identified through the EIS, included:

- water and sediment quality;
- suspended particulate matter in the benthic boundary layer;

- benthic habitat and community;
- shellfish body burden and taint;
- marine mammals, and
- seabirds.

The sampling protocol used a gradient approach. A radial grid with eight axes was centred over the platform and samples were taken along the axes at increasing distances, between 250-m and 20-km from the platform. Water samples were taken in the direction of the prevailing current and Microtox™ testing was used to determine shellfish taint. The monitoring programs are ongoing throughout the project lifetime. SOEI has requested the program be modified to meet ongoing logistical and analytical limitation and to ensure it remains practical.

To date there have been no public releases of procedures or data, an issue of ongoing controversy. It is known that hydrocarbons were detected in mussel samples taken from the jacket legs, but no tainting was found. It was also observed that SBM did not disperse as modeling had predicted, but clumped, moving out only to about 75-m rather than 750 as had been forecast. The resulting "blob" persisted for some time, but then abruptly disappeared, possibly as the result of a storm.

3.1.1.1. Sable Offshore Energy Project Environmental Effects Monitoring Advisory Group (SEEMAG) Results

Review of Tier 1 EEM for SOEP

As a condition of the Development Plan approval by C-NSOPB, SOEI was required to develop and conduct both an offshore and a nearshore EEM program for its offshore natural gas and condensate project near Sable Island. There were four general objectives:

1. improve environmental understanding of cause-and-effect relationships between Project activities and the receiving environment, including both habitats and organisms,
2. provide early warning of undesirable change in the environment,
3. test earlier predictions in order to lower uncertainty or risk, and
4. provide feedback to SOEI, the regulatory authorities, stakeholders and the interested public in order to enhance adaptive management programs and guide environmental protection decisions.

The EEM programs have been overseen by the Sable Offshore Energy Project Environmental Effects Monitoring Advisory Group (SEEMAG).

The SEEMAG had five goals:

1. assist in scoping the EEM program,

2. focus the EEM program on significant issues identified through scientific inquiry, public consultation, or regulatory requirements ,

3. review monitoring studies and comment on their scientific and statistical validity,

4. evaluate program results and recommend improvements to the program and further mitigation measures as necessary, and

5. comment on linkages between the EEM program and Environmental Compliance Monitoring, as appropriate, in the interests of effective environmental management contribute to the understanding of the environmental impacts of the offshore oil and gas industry.

SEEMAG is an advisory body, with members potentially drawn from government, academic institutions, the fishing and aquaculture sector, First Nations, environmental or other relevant organizations.

The Tier 1 offshore EEM program focused on activities at Venture, Thebaud, and North Triumph, before, during, and after drilling. Specific objectives included:

- incorporate public concerns, regulatory concerns and scientific concerns,
- examine the potential impacts of produced water and the potential for tainting ,
- monitor accumulation and movement of drill wastes around the platforms, in particular towards the Gully,
- monitor traffic noise and noise-related SOEP effects on marine mammals,
- monitor nesting and young birds of the Roseate Tern population on Sable Island,
- monitoring:
  - water quality
  - suspended particulate matter (SPM) in the benthic boundary layer (BBL)
  - sediment toxicity and chemistry
  - shellfish body burden and taint.

Results for these over time are summarized in the tables provided in Appendix II. Effects on benthic habitat and megafaunal communities, marine mammals, and seabirds were also reviewed. Sets of questions were defined for several of the key parameters. An overall summary of conclusions for the Tier 1 EEM program, presented to SEEMAG in April of 2001, is provided below:

Drilling Wastes

- Overall much thinner deposits of drilling wastes than predicted were found at each distance from the rig. Drill waste flocs were not spread out as much as the model had predicted, and the drill waste tended to be cohesive and clumped, staying in a narrow pile within 70 to 100-m of the source.

- No tainting or toxicity was found in the survey array close to the platforms (40-150 m), and hydrocarbon levels were consistently very low. Hydrocarbons are detectable at 250-m and 500-m in the direction of prevailing currents at Thebaud and North Triumph but at concentrations approaching background levels.

- Cuttings piles under some rigs lasted longer than predicted; synthetic drilling mud proved very sticky, giving the mounds a plasticine-like consistency and holding them in place.

- Overall, the EIS model overestimated the impact of drilling waste. The input into the model should be adjusted to ensure that the information is appropriate.

Benthic Boundary Layer

- Bentonite-sized particles were not detected in suspended particulate matter extracted from the BBL water samples. The maximum concentration of barium in the suspended particulate matter was two orders of magnitude lower than levels known to cause sub-lethal effects on scallops.

Epifauna and Infauna Communities

- No effect was observed on these communities at any of the survey stations within the Venture, Thebaud or North Triumph fields.

- Video surveys around the platforms show an abundance of juvenile gadoids, mussels and crabs. Colonization of large epibenthic organisms such as starfish, sea urchins, and sea anemones was evident along the exposed portions of the main pipeline. Snow crabs were observed on and along the sides of the gas pipeline and in high densities around the North Triumph platform. Protective mattresses near Thebaud showed numerous sea cucumbers.

Biogenic Hydrocarbons

- Positive odour and taste results were found to be caused by biogenic hydrocarbons occurring naturally in phytoplankton.

Marine Mammals

- Marine mammals observed from fixed platforms were within acoustic range of the sound spectra radiating from the project. Project activities did not seem to affect them.

Seabird Observations

- Flaring has caused no large-scale bird fatalities, and no oiled seabirds on Sable Island contained hydrocarbons attributable to the Tier 1 project.

Monitoring continued at the Tier 1 sites in 2001, although sampling frequency was reduced for a number of parameters. Snow crab sampling began. In 2002, EEM continued, but on a more limited basis. The use of sentinel species was introduced, like snow crab, and, potentially, the Jonah crab found around Venture and Thebaud.

Sampling Design

The initial sampling design consisted of a radial grid with eight axes, with sampling conducted along transects at increasing distances from each platform: 250-m to 20-km. Sampling was initially planned to be carried out quarterly.

Baseline surveys were undertaken in June and July of 1998. Three of the fields were visited: Venture, South Venture and Thebaud, all part of the first tier of gas field development. At Venture, 37 stations were established; the design took into consideration the direction of the currents, toward the Gully. At South Venture there were 35 sites, and at Thebaud 38 stations. There were an additional five Gully sites on the top of the shelf by feeder canyons, not on the slope.

A fall survey in November/December of 1998 collected drilling period data from these three fields, and baseline data for North Triumph. A second drilling survey originally scheduled for February/March was cancelled due to poor weather and the shortage of suitable boats; plans for more winter surveys were dropped. The second drilling survey was conducted in June 1999. Certain parameters, like BTEX, were consistently undetectable. It was noted, however, that BTEX is found in produced water and should be a component of production monitoring.

The main conclusion of the 1998–99 program was that the EIS models considerably overestimated impacts from the discharge of drilling waste. Based on the results of the 1998 and 1999 surveys, trends were identified in the behaviour, distribution, and effects of drilling wastes. A number of issues were re-evaluated as a result: sampling design, water quality, sediment toxicity, and inorganic particle spectral analysis.

Given the evidence of drill waste attenuation along certain axes, sampling location and frequency changes were recommended by SOEP consultants for drilling and operational monitoring in 2000:

- Eliminate far-field minor axes (no significant difference was found)
- Add an extra 500-m to minor axis to improve resolution
- Maintain far field 15-km stations at Venture, and 20-km stations at North Triumph and Thebaud as reference stations
- Eliminate far field stations at 6-km, 7.5-km, and 10-km.
- Maintain 36 to 24 stations at Venture (plus 5 Gully stations)

- Maintain from 39 to 26 stations at Thebaud
- Maintain 38 to 26 stations at North Triumph
- In all three locations, focus sampling within 3-km.

This strategy was said to meet both statistical power analysis requirements, and a recommendation of randomized sampling within a ring which does not give directionality. In 2001, a radial survey array was established for Venture, Thebaud, North Triumph and a remote reference site.

Water Quality and BBL

Water quality issues included:

- Does the BBL flocculate occur in pre-drilling conditions?
- Can BBL flocculate be consistently identified and sampled with existing and available technology?
- What is the spatial and temporal extent of BBL flocculate after drilling operations?
- Has the BBL transport modeling in the EIS accurately predicted the spatial and temporal extent of BBL flocculate?

A baseline program in summer, 1998 analyzed BBL for metals, hydrocarbons, and BTEX at each of the sites on each field and the Gully. An important question was whether barium could be used as a tracer for drilling mud; baseline indications were that barium was randomly scattered around all of the sites. As well, concerns were raised that barium is heavier than other fractions of suspended material and its distribution might not reflect that of the drilling waste as a whole.

An important issue throughout was the validation of the **bblt** model, which predicts drilling waste concentrations with distance. Sample locations were selected on the basis of model predictions. The model predicted that:

- Drilling fines would be carried significant distances at a relatively high concentration (7-mg/L of suspended solids).
- At the Venture and Thebaud fields, for a one-week discharge of SBM, a concentration of 7-mg/L would extend 10-15-km from the discharge.
- Under the conditions of a continuous daily release model scenario, a concentration of 0.1-mg/L of drilling mud fines (measured as barium) would be found 5-15-km from the discharge.

Water quality sampling was completed in fall of 1998 and summer of 1999 at the surface, mid-water and near-bottom at 250-m, 500-m, 800-m, 1000-m and 2000-m along the prevailing current direction. Analyses were undertaken for Total Suspended Solids (TSS); Chlorophyll *a*, Benzene, Toluene; Ethyl Benzene, Xylene (BTEX); and C_6 - C_{32}.

Measurements from the first survey indicated that TSS values were lower than predicted by an order of magnitude. No plumes were visible, and fine particulates settled out at Thebaud within 500-m of the platform. Although not entirely clear, it appeared that the **bblt** model predictions had assumed a continuous discharge of drilling wastes. It was assumed that since suspended particulate matter (SPM) was being measured it must be continuous discharge rather than repeated bulk discharges.

Questions were raised in SEEMAG discussion about the relative merits of continuous water quality monitoring versus tracking of the plume from bulk discharges of WBM. It was agreed that while the model had to be tested, it may eventually be determined that the water quality testing is not worth continuing and that monitoring effort should focus on tracking of the bulk discharge plume. It was also noted, however, that water quality cannot be ignored because of its potential impact on fish.

SEEMAG recommended in November, 1999, that:

SOEI should revisit the **bblt** model to:

- ensure it is up to date,
- clarify whether the model parameters assume bulk or continuous discharge conditions,
- ensure it takes into account the use of SMB and WBM rather than OBM,
- includes produced water, and
- see how much it over-predicts the outcome and whether more realistic results can be obtained.

It was noted that the **bblt** model had undergone further development since the version used for the SOEP EIS. Changes affected the biological interpretation and understanding of sediment rates.

At the same meeting, SEEMAG also recommended that SOEI should evaluate linking water column, BBL and sediment samples in time. SOEI should re-examine the 'snapshot' sampling approach for water quality and determine whether it is worth continuing in the next round of monitoring. There were several conclusions: (1) it would be improved by collecting information about concurrent operational activities, and (2) it only seemed to provide useful information for hydrocarbons in the sediments.

In May of 2000, it was reported that the periodicity shown in the **bblt** tables was tidally-related, and that the key determinant in drilling waste distribution was more likely settling velocity than how drilling waste was released. The model may be overestimating the sedimentation rate; if sediments stay suspended they would not show up in the BBL. The model was designed to give conservative but credible values and not to reflect storm driven environments, which affect the results for shallow water. The monitoring results show that the modeling does not reflect reality, especially in terms of distance from the rig, and the model should be re-examined for Tier 2 monitoring.

It was recommended in 2000 that water quality sampling be reconsidered. No discharges, even of WBM, were planned after January 2000. In 2001, the BBL program became annual, rather than semi-annual, after three years of study had resulted in next to no evidence of drill waste muds.

Sediment Chemistry

A baseline program in summer, 1998 analyzed sediment baseline chemistry for metals, hydrocarbons, and BTEX at each of the sites on each field and the Gully. Grab samples were used; local sediments were very compacted, and a heavy sealed sampler was needed. The challenge was to ensure that the sample did not wash out, losing the flocculant. THC and barium contamination reduced over time at the 250 and 500-m sites, reaching background in 2001 at Venture and North Triumph, although Thebaud still showed some residual elevated THC and barium.

In 2002, sediment chemistry was limited to TPH and barium. Thebaud showed elevated TPH and barium at 250-m, reflecting recent drilling activity, and elevated barium was found at 250-m at North Triumph. Venture samples remained at background levels for both. Overall, much thinner deposits of drilling wastes than predicted were found at each distance from the rig. Drill waste flocs were not spread out as much as the model had predicted, and the drill waste tended to be cohesive and clumped, staying in a narrow pile within 70 to 100-m of the source.

The cuttings piles had different textures, apparently due to the use or non-use of SBM. For example, the cuttings pile at Thebaud, where SBM was used, had a plasticine texture and appeared almost like an artificial reef. It persisted into 2001. The Venture cuttings pile was similar, but persisted even longer, into 2002. It had a decidedly plastic texture, and was covered by protective mattresses. Cuttings of this type may not have been taken into account during EIS modeling. At North Triumph, on the other hand, drill cuttings were much more friable, and no persistent pile developed.

Piles were sampled and bacterial analysis carried out in 2001 and 2002. At Venture, the cuttings pile persisted, with sulphide-reducing bacteria blanketing the sediment close to the jacket. The cause was unclear. Algal growth was seen on the cuttings, sea cucumbers on the mattresses, and crabs on or by the pile.

Sediment Toxicity

Sediment toxicity samples were taken from grabs and submitted to Microtox™ tests. Echinoid fertilization and amphipod survival studies were also undertaken. Echinoid fertilization was tested using pore water, exposing sea urchin gametes and checking for the percentage of complete fertilization. During baseline studies, positive results were found at a number of stations, for unknown reasons. During drilling, the pronounced toxicity predicted to occur within 150 to 300-m did not generally occur, although toxicity was found at two Venture 250-m stations during the June 1999 sampling period, with a fingerprint match of the toxic substance to SBM. However, recurrent problems were found with echinoid fertilization testing, and it was abandoned in favour of the use of amphipods. Echinoid fertilization tests showed no correlation with obvious drilling waste effects, and in general the suite of sediment toxicity tests required review in 2000. Even the amphipods did not provide sufficiently reliable results on their own, although they were useful as a sentinel species. In 2001, sampling frequency was reduced to annual from semi-annual. No amphipod mortality was seen at Venture in 2001, though there was some at Thebaud, along the prevailing current direction. In 2002, amphipod toxicity testing continued, with ammonia and sulphide used to establish cause and effect linkages. Amphipod mortality was found at 250-m and 500-m at Thebaud; no correlation was found with natural ammonia.

Body Burdens

There were no scallop beds in the drilling area, so caged mussels were used for monitoring close to the drilling sites. However, baseline work was carried out on scallops taken from sites north of Venture and south of Thebaud, and at a reference site on Middle Bank. Scallops were analyzed for taint and HC body burden, and some for metal content. No taste difference was found between the samples and a control bought at the Atlantic Superstore. The only odour difference found was between the reference site and Thebaud, thought to stem from the release of dimethyl sulphide due to excessive phytoplankton ingestion. Arsenic, mercury, and cadmium were found at significant levels, but no HC.

In August of 1998, shellfish mooring sites were installed in a progression out from the drilling site, e.g., at Venture at "ground zero", 500-m, 1,000-m, 2,000-m, 4,000-m, 10,000-m, and 15,000-m, stopping when the water depth increased beyond 60-m. Mussels were set out on the moorings. On each one, two sediment traps were installed to catch any flocculant, and a turbidity meter to tie in storm event and sediment transport data. However, the mussel moorings proved to be highly susceptible to loss through vessel interference; for example, only three of eight baseline sets were retrieved in summer of 1998. This loss of gear proved to be an ongoing problem for tainting evaluations. As well, sand tended to inundate the bottoms of the cages if the moorings were left in place too long.

Concentrations of HC detected in mussel tissues were not solely attributable to SOEP HC releases. The highest concentration of aliphatic HC in the base mud oil region was 3.04-mg/L, at 500-m sites. However, flavour and odour was found to be no different from the control samples or those from other sites. In general, finding any correlation between body burden and sensory tests proved problematic. Data seemed to consistently show taste differentiation at 250-m, very little at 500-m, and none at 1000-m, but taste and odour did not seem to relate to body burden.

The review of Tier 1 monitoring at SEEMAG in April 2001, stated that positive odour and taste results were found to be caused by biogenic hydrocarbons occurring naturally in phytoplankton. However, at Venture between November 1999 and February 2000, a change of flavour was detected that at the time had not appeared to be biogenic; SBM and produced water had been discharged at the time. Pre- and post-spawning mussels taste considerably different, so this may have been a confounding variable. Snow crab were added to the tainting and body burden studies in 2001 and 2002, reducing the focus on mussels and scallops. Instead of separate mussel moorings, mussels attached to rig legs were scraped and analyzed; one mooring was retained at the 1000-m site at Venture.

Hydrocarbons and biogenic hydrocarbons were detected in October 2001 and again in 2002. The Venture platform mussels had high levels of interfering material, and Thebaud mussels showed lower level peaks in C_{12} and C_{17} ranges of the same material as at Venture. No taint was detected. The leg muscles of crab sampled in July 2002 showed *Nova Plus* drill mud profiles. Hepatopancreas showed traces of *Nova Plus* as well as unidentified interfering material in the mussels.

Benthic Habitat and Megafaunal Communities

Benthic video and still photography were used to document conditions around the drilling sites. A periodic survey beneath the Venture rig was undertaken by ROV after significant storms. No evidence of drilling muds was found at 250-m from the Venture and Thebaud platforms. Sediments were clean and of consistent grain size at each of 250-m and 500-m axis stations.

At the review of Tier 1 EEM at the SEEMAG meeting in April 2001, it was decided to add snow crab surveys around the rigs, to determine whether they were aggregating there, and what effects this might have, particularly on females. Crab traps were also set at North Triumph.

It proved difficult to evaluate possible changes in benthic diversity; it was hard to measure diversity, and annual sampling did not allow definition of spatial change. North Triumph and Thebaud appeared to have some variability, and diversity was limited at Venture when assessed in 2001. A survey in 2002 detected no significant effects on the benthos beyond the cutting pile.

Marine Mammals

Some noise measurements were carried out via subsurface hydrophones with 10-day storage capacities. The hydrophones were put in place in 1998 just before pile driving began. Detectors were saturated at the nearfield receiver. At two km from the source the peak reading had attenuated to 155 dB, slightly below the threshold for detectable behavioural response of whales, 160 dB. At the far-field, the level was 110-140 dB, just above background of 105-110 dB, but below whale behaviour threshold level. The zone of impact appeared less than two km; noise attenuated faster than the model had predicted.

The model was refined, and additional noise data collected during two jacket installations confirmed the new accuracy. The area of influence on mammal behaviour did not extend beyond 0.5-km from the pile-driving site. Measurements at the Gully, 20–30-km, showed that the noise was detectable, but probably below levels that would affect behaviour.

Observation platforms were set up on the *Rowan Gorilla II*, MV *Magellan Sea*, the helicopter, *Seipem 7000*, and *Galaxy II*. The best sightings came from the *Rowan Gorilla II* and *Galaxy II*. Cetaceans and pinnipeds were observed close to the platforms. Single and social groups of whales were seen, some with calves. A pod of minke whales seemed to be using the platform to concentrate prey for hunting. The platforms did not seem to be detrimental to marine mammals. Daily monitoring and recording of marine mammal observations continued through 2002.

Sea Birds

Observations were made during drilling in 1998 and 1999 from three platforms, one at Venture (*Rowan Gorilla II*), and two at Thebaud (*Seipem 7000* and *Galaxy II*). The data were consistent for the three locations. Four or five species of gulls represented 90 to 98 percent of the sightings. It was hypothesized that the lights might have attracted the gulls, but no conclusion was reached as to whether sightings represented a concentration of birds or not. Some land-based birds were also observed. The number of species varied from 20 at *Seipem 7000* to one at *Galaxy II*. Daily monitoring and recording of seabird observations continued through 2002.

3.1.2. Cohasset Panuke

The Cohasset Panuke (CoPan) program was initiated by EnCana, formally PanCanadian, in 1989, and was completed in December 1999. The EEM program for this project focused on benthic communities, oiled bird and debris surveys of Sable Island and shellfish tainting. The methodology for the program included grab samples to examine the benthos, and surveys on Sable Island; however, only the shellfish tainting methodology has been published. The entire EEM project ran for seven years. The shellfish

tainting study used a gradient approach. Two mussel buoys were deployed at each of 250-m, 500-m, 1000-m, 1500-m and 10-km from the rig. One buoy was placed 10-m above the seafloor and one 10 below the sea surface. Testing for qualitative and quantitative effects was completed at an independent lab two to four times a year.

Oil-based muds were used during CoPan drilling. Some tainting effects were detected in mussels, but were limited to within the 500-m safety exclusion zone. A detailed synopsis of CoPan is not provided here due to its limited relevance to exploratory drilling using WBM or SBM.

3.2. Monitoring Programs for Exploratory Wells

There has only been one exploratory well off Nova Scotia which has had an EEM program in place (H-08). The monitoring program was similar to those designed for production projects, as it was based on VECs and the gradient approach.

3.2.1. H-08

The H-08 well was drilled by EnCana between May and June of 2000. The EEM project was designed to examine chemical, physical and biological features of the seafloor in the areas around the well. The EEM program was carried out during the time of drilling. No data were gathered prior or subsequent to the drilling. Based on the gradient approach, four or eight radia 2,000-m in length and centered on the well were sampled. For comparison, reference stations outside the predicted zone of influence were established.

The emphasis was on testing for a wide variety of potential contaminants, including metals. Tests focused on physical chemistry and cutting piles versus biological analysis. Similar to other EEM results elsewhere, any effects seemed to be limited to within about 500-m of the rig. Fingerprinting of residues also showed some residual Ba detected from Deep Panuke drilling.

3.3. Grand Banks EEM

To date, EEM on the Grand Banks has only been conducted for production developments. Baseline studies have typically preceded the actual EEM. A comparison of the various baseline/EEM studies is contained in Table 3.1. The following sections briefly describe programs for Hibernia, Terra Nova and White Rose. Hibernia baseline data are relevant but were collected a number of years after the initial wells were drilled. It also should be noted that Hibernia is now injecting cuttings and produced water so that there waste streams will be virtually non-existent from now on so that EEM results should be improving for that project. Terra Nova baseline and EEM data were not available to us at the time of writing for this project although we were provided a very brief summary through CAPP. White Rose baseline studies may be the most relevant to the present study because sampling was done after recent drilling activity. Husky kindly provided all necessary baseline data and associated documents for the purposes of this study.

3.3.1. Hibernia

A brief history of Hibernia offshore EEM is encapsulated in Figure 3.1. The study design and preliminary results of baseline studies are briefly outlined below.

Table 3.1. Variables Monitored in Current Grand Banks EEM Programs[1]

Variables	Hibernia Operational	Terra Nova Operational	White Rose Design Phase
Sediments			
Physical/Chemical			
Metals	✓	✓	✓
Hydrocarbons, incl. PAHs	✓	✓	✓
Ammonia and Sulphides	✓	✓	✓
Grain size	✓	✓	✓
TIC/TOC	✓	✓	✓
Toxicity			
Microtox™ screening	✓	✓	✓
Amphipods	✓	✓	✓
Juvenile polychates	✓		*to be determined*
Biota			
Benthic Community Diversity		✓	✓
Fin/Shell fish Body Burden			
Metals	✓	✓	✓
Hydrocarbons (incl PAH)	✓	✓	✓
Fin/Shell fish Taint			
American Plaice	✓	✓	✓
Scallop		✓	
Crab			✓
Plankton/ Chlorophyll *a*		✓	✓
Fish Health			
MFO induction	✓	✓	✓
Gill/liver Histology	✓	✓	✓
Blood tests	✓	✓	✓
Seabirds/Marine Mammal Observations[2]		✓	✓
Water Quality			
CTD/TDS/TSS		✓	✓
Hydrocarbons, Total Oil and grease, PAHs, metals		✓	✓

Source: Courtesy of D. Taylor, Husky

[1] Note that this listing does not consider potential Spill EEM programs.
[2] Not, strictly speaking, EEM.

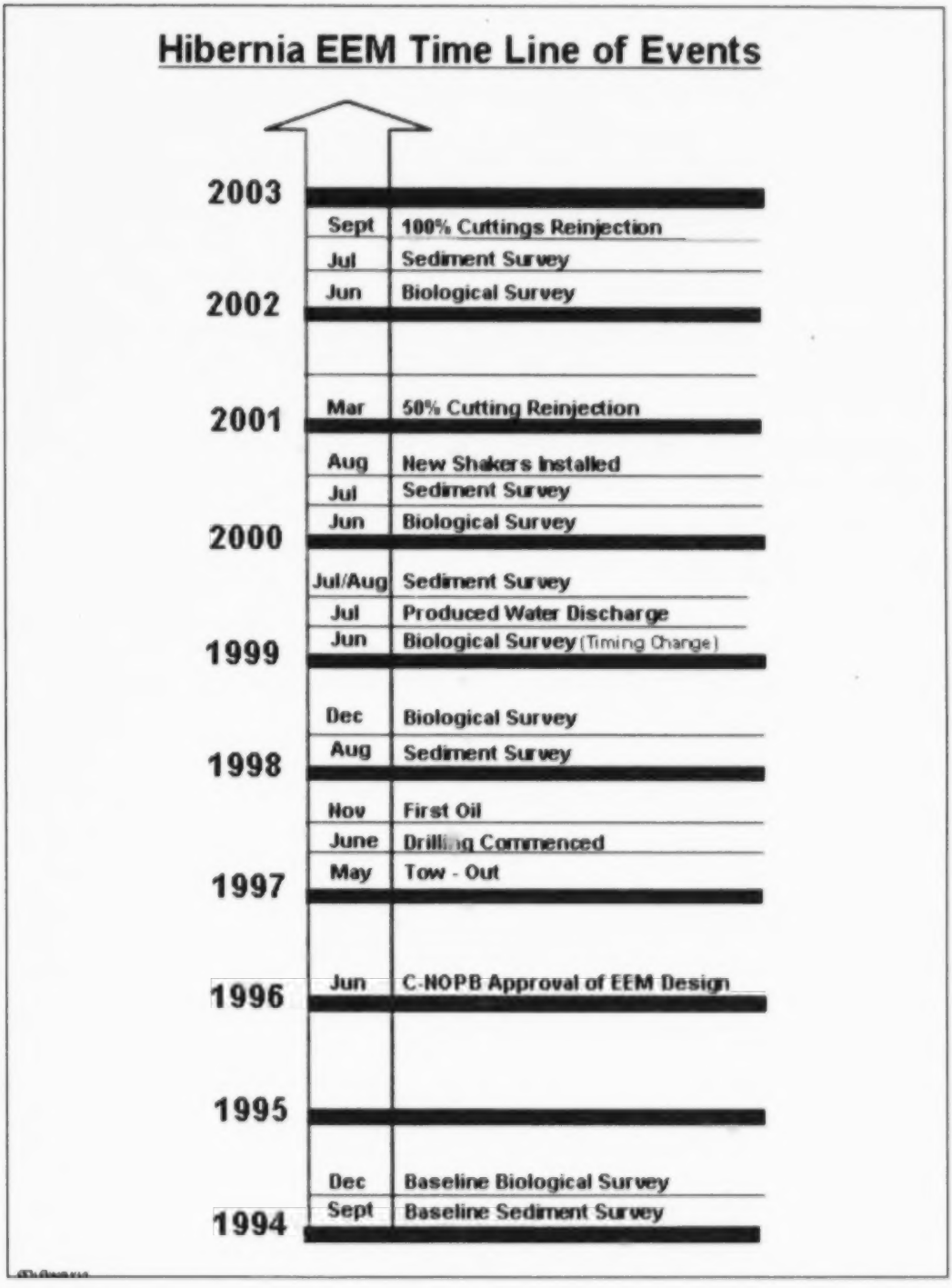

Figure 3.1. Hibernia EEM Time Line.

Source: Courtesy of R. Dunphy, Hibernia.

3.3.1.1. Study Design

Sediment sampling was conducted along eight radii at geometric progressive distances from the GBS and at some random locations (Figure 3.2). Sampling was more intensive close to the GBS. A total of 45 locations were chosen within the concentric circles around the GBS with a maximum radius of eight km. Two 'control' stations were established on the north and west radials at 16-km distance for a total of 47 sediment sampling stations.

Sampling was conducted for the following variables:

- Trace metals (mercury, chromium, copper, lead, zinc, cadmium, arsenic, barium)
- Petroleum hydrocarbons
- Polynuclear aromatic hydrocarbons (PAHs)
- Sediment particle size distribution
- Total organic/inorganic carbon
- Sediment toxicity tests (Microtox™, Toxi-Chromotest™, Amphipod Survival, Echinoid Fertilization (subsequently dropped due to technical difficulties), and Juvenile Polychaete Growth Test)

Sediment was sampled using box cores. Two or three box cores were conducted per station; each one was subsampled three times to create 441 samples. The three subsamples from each core were composited to yield 162 samples for chemical analyses. Material from box core samples was combined to create 54 samples for sediment bioassays. Strategy for the toxicity testing is shown in Figure 3.3.

The biological survey for American plaice (*Hippoglossoides platessoides*) and Icelandic Scallop (*Chlamys islandica*) was conducted within a fishing zone of 500-2,000-m around the GBS and at a reference site 50-km northwest of the GBS. Fishing was not conducted to the south east of the GBS in order to accommodate flowlines and the offloading system. [Note: problems with getting enough of either species; scallops subsequently dropped]. Fish were tested for contaminant body burden and sensory organoleptic analysis (i.e., taint).

Additional detail on methodology and results of the baseline surveys is contained in HMDC (1995) (now publicly available after seven years).

3.3.1.2. Hibernia EEM Results

In some respects, the initial baseline monitoring at Hibernia can be considered a type of check on the effects of exploratory drilling (10-14 years after the drilling) as at least 11 wells were drilled in the area of the baseline sampling. The results of the Hibernia baseline (HMDC 1995) are outlined below.

There were no detectable differences (including statistical) between the GBS and reference ('control') areas in:

- Both lethal and sublethal toxicity testing

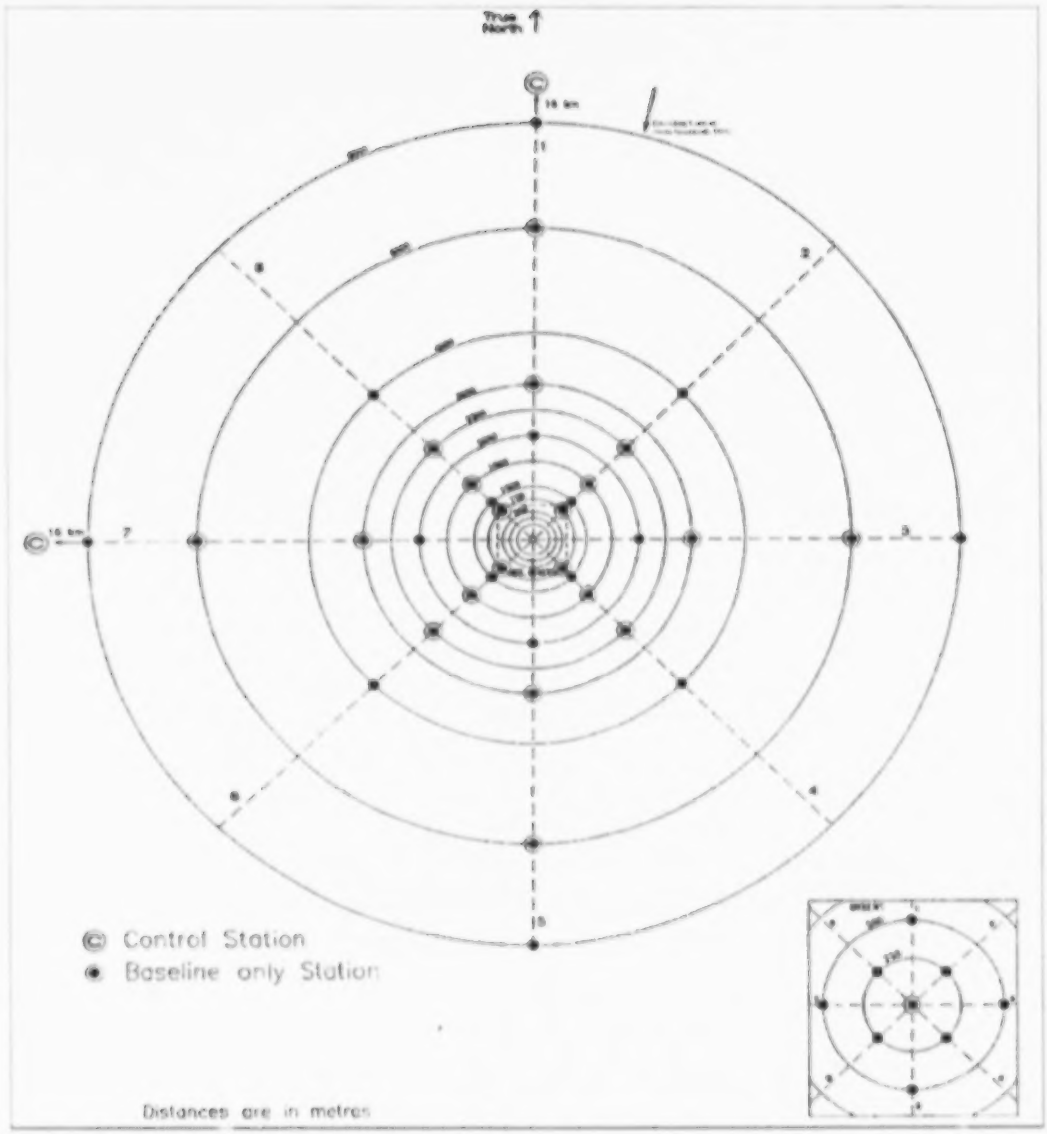

Figure 3.2. Hibernia Sampling Pattern.

Source: HMDC (1995).

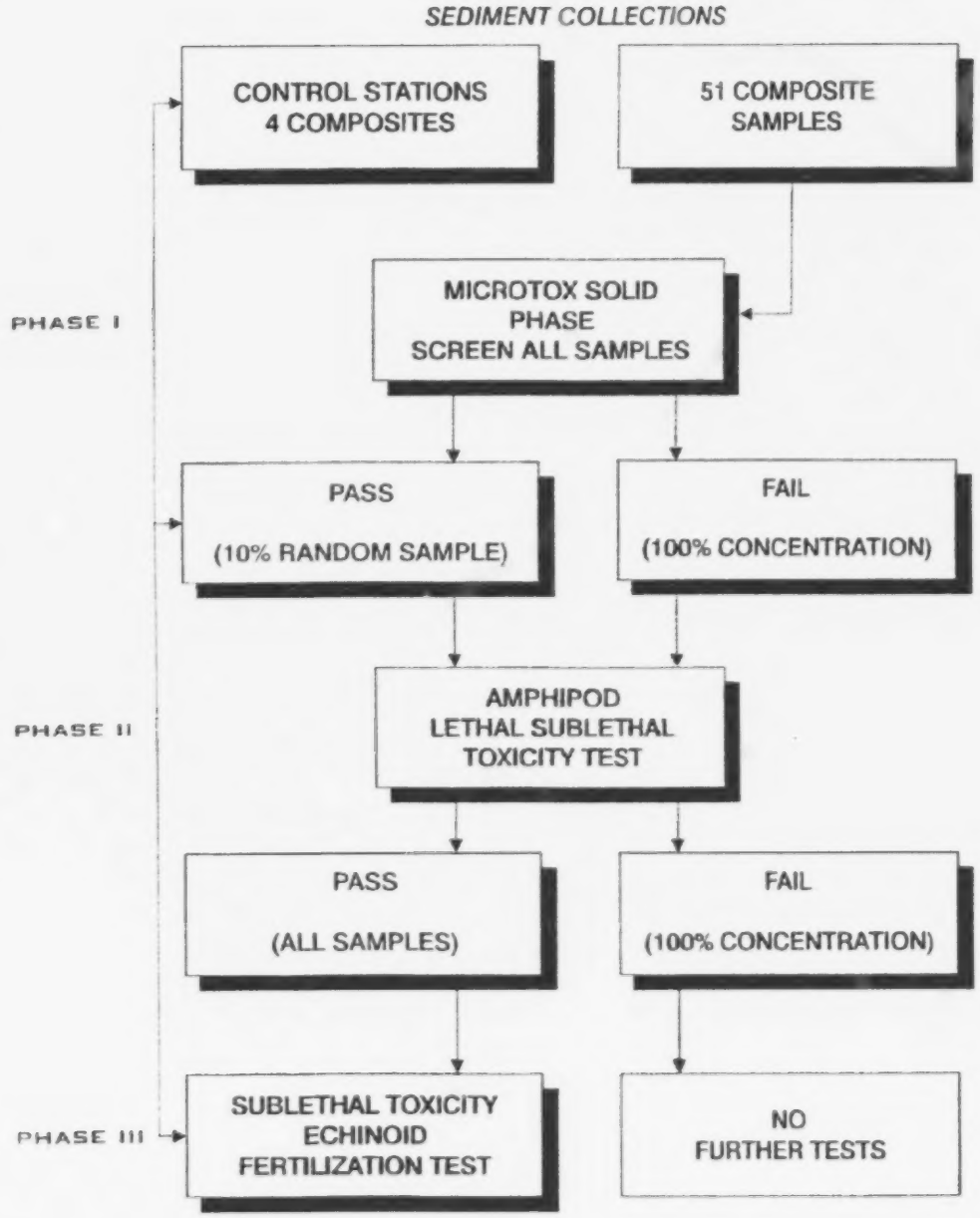

Figure 3.3. Sediment Testing Protocol.

Source: HMDC (1995).

- Tainting in fish and scallops
- PAHs or petroleum hydrocarbons (actually undetectable in both GBS and reference areas at the level of analyses used)
- Contaminant body burdens were generally low for plaice and scallop but insufficient sample sizes precluded definitive statements on body burdens of contaminants.

'Sediment chemistry data show generally low concentrations of all potential contaminant metals. Only two elements, barium and lead, were consistently above analytical detection limits. Slightly anomalous concentrations of barium, lead and, possibly copper were detected at locations 7-2000, and 7-3000' (HMDC 1995). These 'high' values are likely attributable to past drilling activity; for example, the baseline sampling overlies an area where 11 wells had been drilled prior to the 1994 baseline sampling effort. Station 7-3000 is very close to Hibernia Well O-35.

Twenty wells have been drilled from the GBS as of 2000. All upper holes were drilled with water based drilling mud (WBM) whereas 65% of the lower hole sections have been drilled with synthetic based mud (SBM). Hibernia (R. Dunphy, pers. comm.) kindly provided the following synopsis for this period. The EEM program detected elevated barium and hydrocarbons in some sediment samples out as far as 8,000-m from the GBS, but most samples with elevated levels occurred within 500-m of the GBS. Toxicity tests found no acute effects on amphipods beyond 1,000-m and no sublethal effects (as measured by Microtox™ and/or juvenile polychaete growth assay) beyond 4,000-m. There was no significant increase in body burdens of contaminants in American plaice and no tainting was detected. As noted above, Hibernia started 50% cuttings re-injection in 2001 going to 100% in 2003 and thus concentrations of contaminants and any associated effects are expected to decrease.

3.3.2. Terra Nova

The Terra Nova development has planned a total of 24 wells. The Terra Nova baseline and EEM results were not available at the time of writing. The EEM study design is briefly outlined below.

3.3.2.1. Study Design

The basic design is composed of sampling gradients along three transects passing through the drill centres and the FPSO. Stations were placed 250, 500, 1,000, 2,000, 4,000, and 8,000-m from the drill centres in two directions

Variables monitored include:

Commercial species (Icelandic scallop and American plaice)

- Tainting
- Body burden (metals, PAH, petroleum hydrocarbons)
- Health (MFO, liver and gill histopathology, haematology)

Water quality

- Chemical (TSS, metals, PAH, oil and grease)
- Physical (temperature, salinity)
- Phytoplankton (chlorophyll)

Sediment quality

- Chemical and physical characteristics (metals, hydrocarbons, particle size, TIC and TOC)
- Toxicity (sublethal – bacterial luminescence test; lethal – amphipod test)
- Benthic communities (species, enumeration, total biomass) for diversity

Seabirds and marine mammals are also surveyed under a different program (not strictly speaking EEM).

Commercial species are collected within the Terra Nova area and from two reference areas 20-km to the southeast and southwest. Water quality sampling is conducted at four stations around each drill centre and the FPSO. Sediment quality is collected from 50 stations along gradients from the FPSO and each drill centre.

To aid in developing the EEM design, Petro-Canada undertook a Baseline Characterization Program in the fall of 1997 (Petro-Canada 1998 *in* Petro-Canada 1999). The results of this program were as follows.

- Most metals and hydrocarbons were below the limits of quantification (LOQ).
- Sediments were generally non-toxic; some toxicity was observed but this was attributed to natural anoxic conditions at a few stations.
- Benthic communities were patchy and variable in nature, at least partly attributable to substrate characteristics.
- The sediment quality triad (SQT) approach was used whereby synoptic data on sediment characteristics, toxicity, and benthic infauna are analyzed together.
- Water column profiles and water quality variables (few above the LOQ) were similar between the Terra Nova study area and the 'controls'.
- Biological attributes were similar between Terra Nova and controls. Most body burdens were below LOQs and there were no indications of tainting.
- Mixed function oxygenase (MFO) activity was similar between Terra Nova and controls. Fish gills and livers appeared normal in terms of pathology.

3.3.2.2. Terra Nova Results

Sampling for Terra Nova EEM occurred in 1997 (Baseline) (about nine exploration and delineation wells drilled prior to sampling), in 2000 (an additional three development (plus several abandoned) wells drilled prior to sampling), in 2001 (six development wells plus three abandoned drilled prior to sampling), and in 2002 (two or three development wells drilled prior to sampling).

Results (2000, 2001) are summarized below (*per* d'Entremont 2003).

- No tainting detected
- No PAHs detected in sediments, scallops or plaice
- Hydrocarbons (fuel range) and barium in sediments slightly higher near drill centres but still orders of magnitude lower than those required to cause biological effects. No detectable other physical or chemical effects on sediments.
- Slightly elevated hydrocarbons and barium in scallops near development. No other metals elevated in scallops or fish.
- No Terra Nova hydrocarbons detected in plaice
- No differences in fish health variables, water column, or phytoplankton biomass between development site and reference sites
- Benthic community structure appeared similar between baseline and 2000 but slight change in 2001
- Overall EEM results similar to baseline

3.3.3. White Rose

Husky has not yet conducted an EEM program for White Rose because production has not yet begun and thus the EEM design has not yet been finalized. Husky conducted a Baseline Characterization Program in 2000 (Husky 2001b; Husky 2003b) that had many of the components likely to be in the final design. The White Rose baseline results are highly relevant to the present study because much of the sampling was conducted amongst recently drilled wells (Figures 3.4 and 3.5).

3.3.3.1. Study Design

The White Rose study design included a series of grids centered on the future FPSO location and proposed glory hole locations. A total of 50 stations were used for sediment sampling (Figure 3.5). [Note there appear to be discrepancies in the report where the text states 50 or 48 stations, their Figure 2-1 shows 46 stations, sediment toxicity is reported for 48 stations and their Appendix A lists 49.] Sediment sampling included variables for physical, chemical and biological characteristics. Sampling was done using a box corer. One sample was analyzed from each station.

American plaice and snow crab were collected by trawl from the White Rose study area and the northwest reference area (plaice only in 2000) in 2000 and 2002 (Husky 2001b, 2003b). These samples were used to analyse body burdens, histopathology, MFO, tainting and other biological variables.

Figure 3.4. Locations of White Rose Wells and Baseline Sampling Stations.

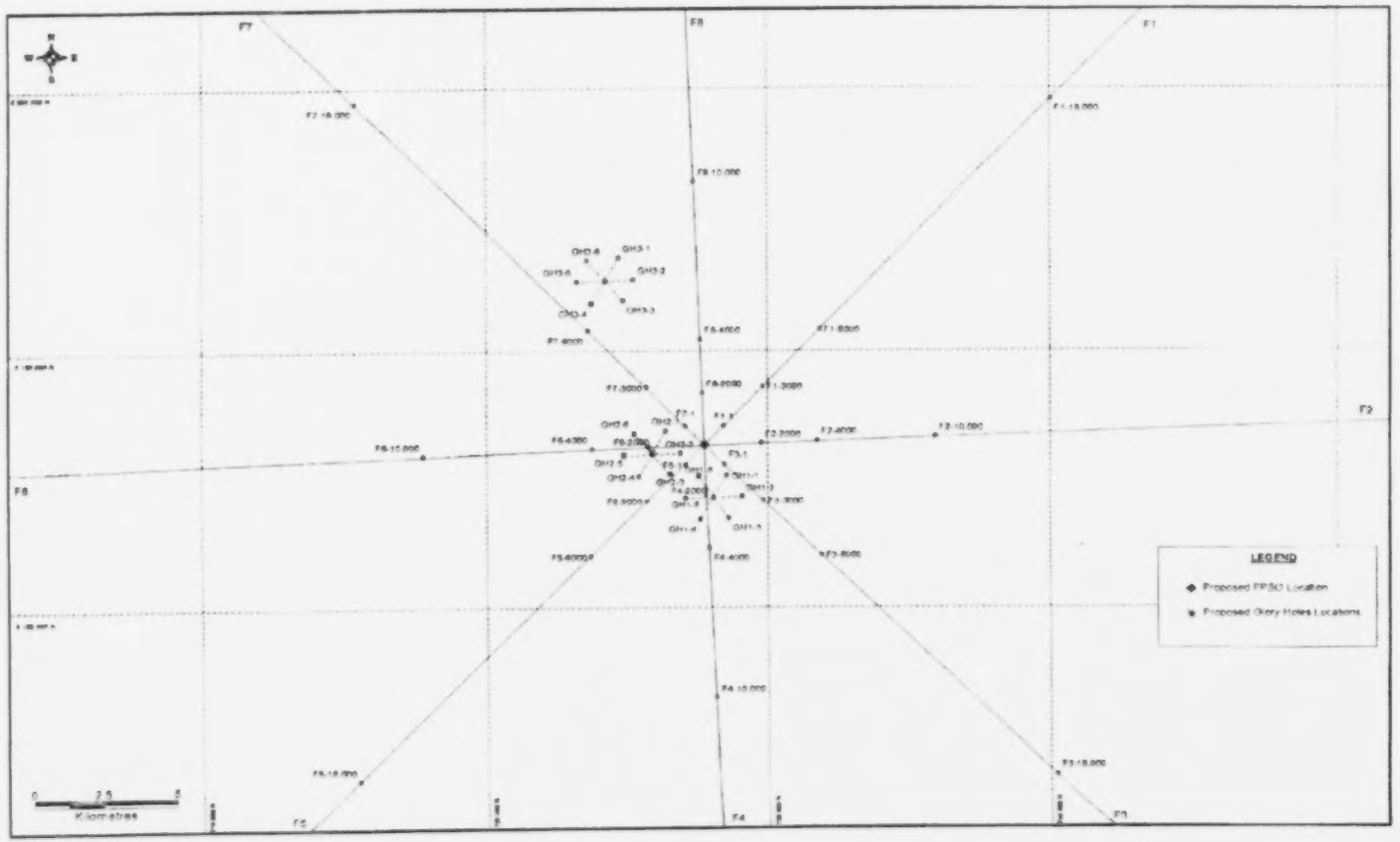

Figure 3.5. White Rose Sampling Pattern.

Source: Husky (2001b).

Variables included:

Sediments
Particle size
Chemistry (metals including barium, PAH, TPH, and oil and grease; TIC, TOC, TC)
Toxicity (amphipod survival-lethal, bacterial luminescence-sublethal)
Benthic infauna (determined species present, abundance, total biomass; subsequently analysed for number of organisms per station, wet weigh of invertebrates per station, number of taxa per station, species diversity, and community composition)

Water Quality (at 25 of 50 stations)
Temperature
Salinity
Oxygen
pH
TSS
Metals
TPH
Oil and grease
PAH
Chlorophyll

Fish Health (American plaice and snow crab)
Body burden
Tainting (plaice only)
Histopathology and MFO (plaice only)

3.3.3.2. White Rose Results

3.3.3.2.1. Sediment Quality

Sediments were primarily sand with some gravel; silt and clay generally accounted for less than 1% of the sediment and TOC was low in both the study and reference areas (Husky 2001b). PAHs were not detected above the LOQ in any sediment sample. The only hydrocarbon above the LOQ (ELQ) was naphthalene. Metals above the ELQs included aluminum, arsenic, barium, chromium, cobalt (not in NW reference area), iron, lead, manganese, nickel (not in NW reference area), strontium, thallium, uranium, vanadium, and zinc. Not surprisingly, concentrations of most metals, including barium, were higher in the finer sediments with higher organic content. Water depth and distance appeared to be more important than direction although depths and direction were confounded to some degree, particularly in an E-W direction. In spatial regressions, only water depth effects were significant for % fines, which increased with depth. There was high variability with the other physical and chemical characteristics around the glory hole locations even though depths were similar. TOC was not affected by any of the spatial variables.

Barium concentrations significantly increased with increasing depth and from south to north, and decreased with distance from the FPSO location and from west to east. Concentrations are shown in Figure 3.6.

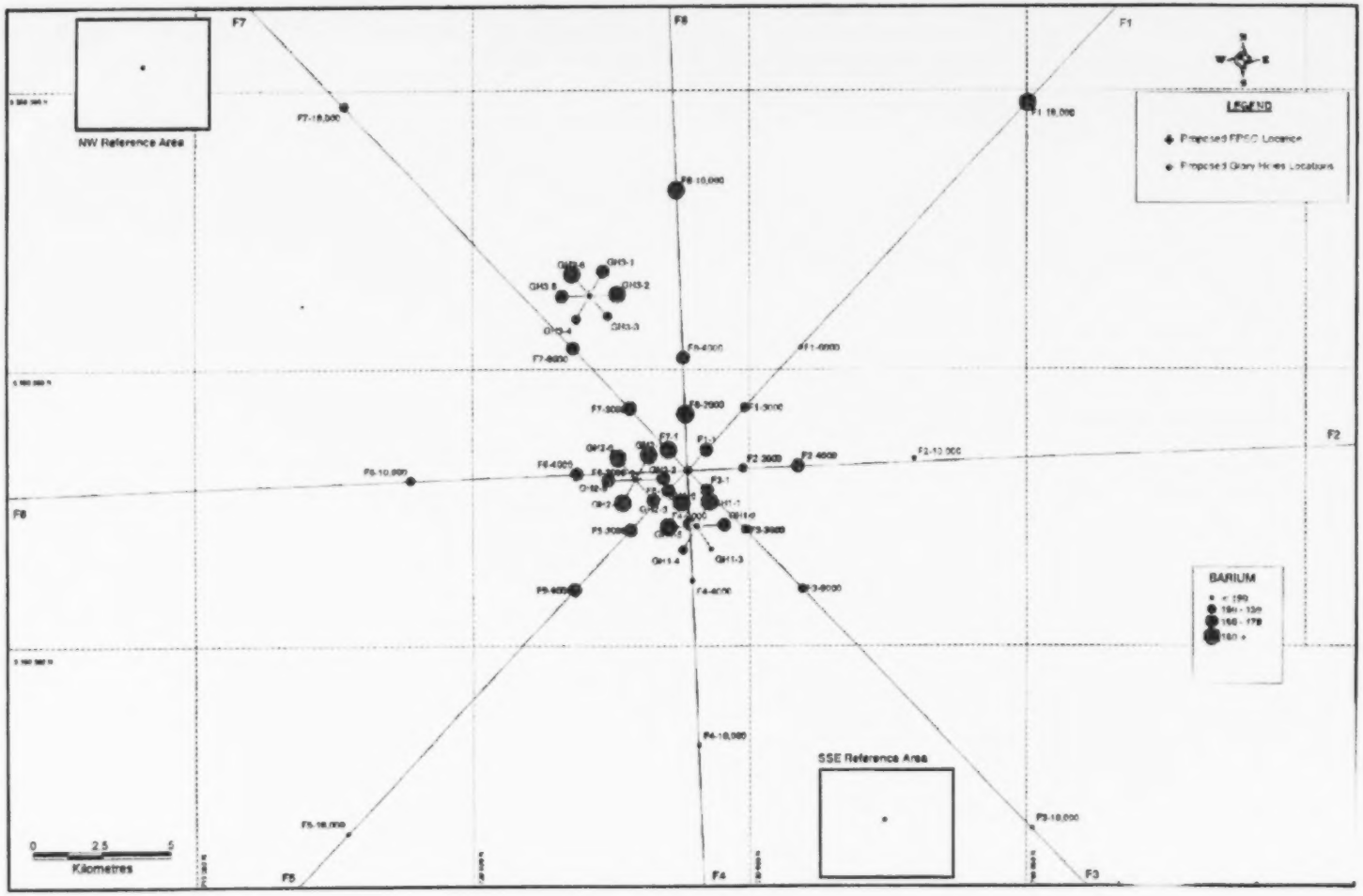

Figure 3.6. Barium Levels in Sediment for White Rose Baseline Characterization Program 2000.

Source: Husky (2001b).

Based on the amphipod toxicity test (acute lethal test) and the Microtox™ test (sublethal test), none of the sediments tested could be considered toxic. Lowest survival rates in the amphipod test tended to occur around the glory hole locations.

3.3.3.2.2. Water Quality

Water quality results were variable and no noteworthy trends were apparent. There were no differences between the reference and study areas in structure of the water column.

3.3.3.2.3. Infaunal Communities

Infauna was diverse (63 families) but dominated by polychaetes which accounted for about 80% of the organisms collected (excluding oligochaetes, nematodes and nemerteans). Communities at the reference areas were different than those in the study area. In general, there was a high degree of variability among all benthic infauna variables except standing crop. The effects of distance and direction from the future FPSO site on benthic infauna variables were stronger, and water depth effects weaker, than for sediment physical and chemical characteristics (Husky 2001b).

3.3.3.2.4. Body Burdens

Body burden analyses were based upon relatively few composited samples (only 3-5) with varying numbers of animals per composite. With the exception of manganese, arsenic, cadmium, copper, iron, manganese, mercury, selenium, and zinc were present in all samples of plaice livers. Arsenic mercury and zinc were found in all plaice fillets, and, metal concentrations, with the exception of mercury, were generally higher in livers than fillets.

Arsenic, boron, copper, mercury, selenium, strontium, and zinc were found in all snow crab leg samples. Cadmium and silver were detected in two samples in 2000.

In general, results were similar between the study area and the reference areas although strontium was very high (relative to other samples) in a snow crab sample from the Northwest Reference Area.

3.3.3.2.5. Tainting

Tainting as tested by taste panelists was not detected in any samples from the study area or the reference areas.

3.3.3.2.6. Fish Health

In general, the fish health component of the study documented background levels for external lesions, histopathology, and hepatic MFO. Several fish were noted to have lesions potentially indicative of contaminant stress (Husky 2001b).

3.3.3.2.7. Important Conclusions

Conclusions included:

- NW reference area sediments were found to be quite different from the study area and were excluded from much of the analyses. This station should be dropped.
- For the most part natural variability can be accounted for in subsequent samplings.
- Many sediment characteristics varied widely even at the closest (1-km) stations. Particle size and TOC had least amount of variability.
- Number of stations (46-50) appeared to be adequate.
- Sufficient numbers of organisms and taxa were collected per core to conduct statistical analyses. Replicate cores are not required for benthic analyses if stations are considered as replicates. Increases in power decrease rapidly for sample sizes greater than 20, and particularly after 50.
- Numbers of body burden samples may have been too small; need at least five samples per area. Fish health work should be conducted on the same specimens, if possible.
- The SQT approach looks good, as there were no 'false positives.'
- Water quality sampling was of limited utility.

4.0 East Coast Issues

4.1. Issue Scoping

Informal interviews and meetings were held in Newfoundland and Nova Scotia with a variety of interested parties, including representatives from the regulatory sector, offshore oil and gas industry, fisheries associations, NGOs, and scientists. Interviews focused on three main issues:

- Is EEM required for drilling a single exploratory well off the East Coast? If so, under what conditions? If not, under what rationale for exclusion?
- What are the key variables/issues?
- Any study design suggestions?

Detailed results and analysis are presented in Appendix III. The results of the interviews were quite different for Newfoundland versus Nova Scotia; this section reviews the main themes that arose, and the commonalities and differences between the regions.

4.1.1. Newfoundland

Discussions in the Newfoundland region focused on 29 issues, some of which overlapped. Issues raised by participants fell into several general categories:

- Overall monitoring program design issues;
- Site-specificity of monitoring design;
- Logistics and efficiency, and
- Public policy concerns.

Most issues, discussions and suggestions in regard to a study design for exploratory EEM were general, as opposed to specific scientific recommendations.

There was an overall sense that the present EEM programs were well designed and were providing useful information on the effects of the producing developments at Hibernia and Terra Nova. Respondents thought that production EEM program designs were good starting points for exploratory drilling EEM, if it were to be conducted at all.

There was agreement that local environmental conditions, particularly water depth, currents, and the presence of corals, must be considered in any offshore EEM program. Any critical habitats should be identified during the EA process and avoided. If they cannot be avoided, then the EEM program should be enhanced as appropriate.

Similarly, site-specific drilling scenarios need to be considered in the design. For example, while different rig types have generally similar discharges their depth of discharge may vary. Also, 'jack-up'

and semi-submersible rigs emit less noise than drill ships. The type of drill mud (water-based vs. synthetic) used may affect the distribution of potential contaminants and hence should influence the sampling design.

Most participants felt that monitoring program design should be flexible to account for unforeseen events. Flexibility may be a more important issue for exploratory EEM rather than production, because of the much shorter lead times.

Opportunistic bird and mammal surveys presently being conducted from supply boats at Hibernia and Terra Nova were viewed favourably, although most agreed that they are not, strictly speaking, EEM but rather general survey data. It was, however, pointed out that such data are of limited use unless they are publicly available and analyzed and interpreted into useful reports. Virtually every non-industry person stated that the EEM data should be available to the academic community, industry researchers, EA practitioners, and the general public much sooner than the now regulated under the *Atlantic Accord* five-year confidentiality period.

The suggestion that cumulative effects be considered under the auspices of exploratory EEM is also one that warrants discussion; one well may have little or no effect but a large number of them might, depending upon timing, local conditions, and other factors.

4.1.2. Nova Scotia

Most interviewees agreed that EEM programs should be a routine part of offshore drilling, whether for exploration or production. However, there were sharp difference among them regarding the reasons for monitoring, conceptual design, funding, and program implementation and interpretation. These differences were not merely between sectors, but also between individuals and organizations within the different sectors.

Most, but not all, agreed that environmental concerns are lower for exploration drilling than for production platforms. They saw the wells as having little or no effect, especially in the long term and when located in habitats with few or no sensitive features. Those who held this view agreed that conceptually, EEM should focus on looking for real consequences. The EEM projects need to be species and site-specific, ideally monitoring different trophic levels.

However, some interviewees feared that exploration wells could have serious environmental effects, particularly when considering cumulative impacts. Many of these respondents felt that EEM requirements should be the same for exploration wells as for development platforms.

Some respondents urged a decision tree approach to designing monitoring programs, keeping options flexible to reflect local conditions. Several felt strongly that efforts had to be geared toward the scale of activities, with less detail expected for exploration wells than for development platforms.

The C-NSOPB would like to see a class screening approach to exploration drilling, rather than a comprehensive study required for every well, and good EEM data are required to satisfy *CEAA* that this would be an acceptable approach. As well, a number of government, industry, and academic respondents thought there was considerable merit in the idea of implementing full EEM programs at several sites on the Scotian Shelf and Slope that represented common habitat types; other wells in

similar habitats would then rely primarily on the representative site results. However, others from the same sectors felt strongly that monitoring had to be entirely site-specific, and full programs were needed for each project.

Most respondents agreed that a major function of EEM was to test predictions made in an EA; many of these also stressed the need to verify modeling predictions. A few, however, thought it should go beyond, and comprehensively survey outputs and effects, even if these were permissible under the *OWTG* or had not been judged to be of concern in the EA.

There was a basic disagreement between those focused on identifying and monitoring discharges, and those who were concerned primarily with the biological effects of discharges. Some NGO, fishing, and scientific respondents wanted everything that a rig discharged monitored for fate and ecological effects; others thought this unnecessary. Industry, in general, was of the opinion that monitoring had to go toward verifying EA predictions, and document once and for all the levels and severity of impact of exploration drilling.

One DFO scientist strongly argued that identifying impacts on organisms, and then figuring out what is causing the impact, should be the primary focus of EEM. A number of other respondents concurred that the existing focus for EEM has been, and is, on measuring contaminant levels rather than biological effects; there is a need to develop effective technologies to assess the latter.

Numerous respondents insisted that any environmental data collected from industry monitoring programs should be shared and released to the public. Some industry representatives raised concerns about confidentiality and expense, as well as how to manage data distribution.

The existing offshore EEM programs for oil and gas projects have been designed to examine the VECs identified during the EA process, while also taking into account those concerns expressed by the community. Monitoring programs that were most successful, with accepted results, were those that had baseline data to measure against.

A number of respondents raised concerns about cumulative impacts, and how to identify interactions between projects. It was stressed that the offshore oil and gas industry should not be taken in isolation, but cumulative and regional impact analyses needed to include shipping, fishing, and research as well.

Benthic effects were generally seen as most important, although other issues commonly raised were impacts on marine mammal, bird mortality/attraction, impacts on finfish, and air quality. Most agreed that concerns about toxicity of drilling wastes were at a lower level now than in the past, although there remain questions about the effects of synthetic muds.

Most respondents agreed that there were differences between monitoring in deep water versus shallow water sites. Some potential monitoring elements for deep-water sites include amounts and distribution of cutting piles, and biological effects from drilling. Instrumentation development is a real issue for deep-water sites, as are good models for sediment transport. At shallow water sites, wastes accumulate or reach shorelines more easily, depending on oceanographic conditions.

Sediment sampling and chemical analyses, while expensive, are probably the easiest monitoring methods to establish changes to the seabed. However, is it the most effective at establishing actual

resulting impacts? It was strongly suggested by several respondents that the use of bivalves in cages on the seabed, with an appropriate local indicator species, was the preferable way to identify biological effects. Cages should go down before drilling starts and come up when done; "EEM should be kept that simple unless effects are seen," urged one scientist.

Even those who strongly believed impacts on fish should be monitored had difficulty suggesting concrete methods that would be successful in establishing effects. Some felt that reviewing water quality around an exploration rig would help identify any impacts on fish. Some suggestions for monitoring sub-lethal fish impacts were: tissue chemistry studies, histological analysis, the use of tracers in drilling fluids, assessment of condition before and after, analysis of population age at the site, and fecundity and age size.

Testing of the assumption that birds and marine mammals are attracted to rigs could use a simple program taking advantage of the helicopter supply runs, one respondent suggested. Each run could be varied by direction to the rig; time of day and sea bird/mammal counts could establish if the rigs act as attractants.

One academic scientist strongly urged carrying out comprehensive ROV surveys and other baseline work for every well, following protocols of Kostylev et al. (2001).

Respondents concurred that statistical validity is absolutely crucial to EEM. It was suggested that revisiting sites after a year (and, if effects were detectable, after two) would be useful to accurately determine if there were long-lasting effects.

An offshore oil and gas industry respondent suggested that fishing activity and catch rates could be monitored by keeping in touch with area fishermen by radio while drilling proceeded.

One NGO respondent strongly believed that the essence of environmental concerns on the offshore centered around the license-issuing process, and the quality – or lack thereof – of the Strategic Environmental Assessments. NGO respondents raised the Gully as a particular concern, suggesting that permanent monitoring sites should be established in it to pick up sediment transport, if any.

5.0 Comparisons: Newfoundland and Labrador vs. Nova Scotia

It is difficult to directly compare the issues as they are perceived in Nova Scotia versus those in Newfoundland and Labrador for a number of reasons. The interviews and meetings were intentionally informal and unstructured, which is good for soliciting input but also means that care must be taken in weighting one issue over another. Furthermore, in the interest of cost efficiencies and local knowledge, different people conducted the interviews in the two provinces.

There are also obvious differences in demographics between the two regions and important differences in environmental conditions and development scenarios. Nova Scotia to date has developed gas mostly in shallow water using 'jack-up' rigs whereas Newfoundland has developed oil at moderate depths using the Hibernia GBS, semi-submersible drill rigs, and FPSO's. However, development scenarios may be moving into deepwater in both locations. Nonetheless, it is worthwhile to reflect somewhat on the differences and similarities between the two regions.

5.1. Some Differences in Perceived Issues

There were, of course, differences between respondents in their perceptions of the issues and of the best species to monitor. These differences appeared to be much more pronounced in Nova Scotia than in Newfoundland and Labrador. Without putting too fine a point on the differences between the different regions, there appear to be the following differences in regard to exploratory drilling EEM.

- **Emphasis on benthos.** Both regions agreed that benthic environments are key in monitoring the effects of offshore oil and gas because of likely contaminant pathways, relative sedentary nature of benthos, and relative ease of sampling. Fate and extent of cuttings piles, barite residues, and hydrocarbon levels were mentioned by many. However, there appeared to be much more emphasis on benthic monitoring for exploration wells in Nova Scotia. This was evident in concern for effects of barite, the benthic boundary layer, deep sea corals, and so forth (see below).

- **Emphasis on fish.** In general, the Newfoundland Region appeared to place more emphasis on fish and related issues than Nova Scotia. In Nova Scotia, there is, and has been, more emphasis on shellfish. There has been considerable study on scallops and monitoring programs have used scallops extensively; at least one project used caged mussels extensively.

- **Degree of monitoring.** While there was a wide range of opinions in both areas, there was a wider range in Nova Scotia and two clearly defined groups: (1) the 'monitor everything' group, and (2) the 'monitor select variables' one. In Newfoundland, individuals and groups appeared more focused and no one advocated monitoring everything.

The generally higher interest in benthic issues in Nova Scotia is at least partly attributable to differences in substrate, water depth, and water current regimes. In addition, the shellfish industry (excluding crab) is significantly more important off Nova Scotia than off Newfoundland. Demographics and research interests of individual scientists also undoubtedly played a role.

5.2. Some Similarities in Perceived Issues

Some important common points of view found in both areas are listed below.

- **Level of concern with exploration drilling**. Although there were some exceptions, most people had a much lower level of concern for the environmental effects of a single exploratory well than for a production development.

- **Assurance monitoring.** While some argued strongly for extensive statistical work, there still was a common thread that most people wanted some level of reassurance that a specific site was not being unduly affected. A number of people suggested some camera drops and some grab samples might be enough to accomplish the goal of providing a suitable level of comfort.

- **Testing EA.** A number of participants suggested that one of the key functions of a monitoring program is to test predictions, and in some cases modeling, that were conducted during the EA process. A potential corollary of this attitude is the suggestion by some that one or several wells should be selected as 'test cases' and monitored possibly in aid of a Class or Generic EA approach. This would provide rationale for including or excluding monitoring variables for future individual wells.

- **Biological effects**. With some exceptions, most felt that any monitoring programs should focus on biological effects as opposed to simply 'shopping' for increases (however slight) of potential contaminants.

- **Birds and mammals**. Many agreed that there were potentially important issues in regard to marine birds and mammals. However, it was also pointed out by a number of people that routine surveys conducted from the rig or supply boats do not necessarily constitute any monitoring of effects *per se*.

- **Site specifics.** Local and site specific issues must be considered in the design and conduct of any EEM. This was a virtually universal comment. There is awareness in both locations of some potential for different issues in deep versus shallow drilling scenarios. To date, however, the depth differences have been most apparent off Nova Scotia where most wells have been drilled in shallow water or increasingly in deepwater.

- **Data availability.** Almost everyone stated that availability of EEM data is an important issue. At present, the *Atlantic Accord* allows a development to hold the EEM data confidential for five years. In fact, availability of data was an issue with the conduct of this study.

- **Cumulative effects.** While many were not particularly concerned with the effects of one exploratory well, they suggested that a large number of single wells could be an issue, particularly if they were within a relatively small geographic and/or time frame. On the other hand, no one had any ready solutions to this problem.

6.0 Application of Production EEM Experience to Exploratory Drilling EEM

The offshore production EEM experience developed on the East Coast over the last 10 years or so is applicable to EEM for exploratory drilling as representing a 'worst case' scenario. The production EEM programs were developed for large multi-well, multi-year projects that have more potential to affect the marine environment than a single exploratory well, which is small scale and often dry. Big developments such as Hibernia or SOEI entail the drilling of multiple wells, underwater excavation and infrastructure, loading and unloading of hydrocarbon products over a long period of time, the discharge of produced water, and so forth. As a result, the discharges, effects, and measureable 'footprint' will be different by orders of magnitude. One scientist likened it to a 'footprint' versus a 'fingerprint.' Nonetheless, based on the review of information and consultation with numerous interested and knowledgeable parties, the following conclusions can be drawn.

- Aside from a large oil blowout (a very unlikely event according to previous EAs) and a few other special cases, any effects from an exploratory situation are of much less concern than a production scenario.

- In general, the production EEM programs completed to date are viewed as adequate for confirming EA predictions and in providing a level of assurance that the East Coast marine ecosystems have not been significantly affected to date. They have also served as testing of techniques for use in EEM off the East Coast.

- Baseline studies conducted by Hibernia, Terra Nova, and White Rose can provide valuable insights into the effects of drilling because these studies were done at varying periods of time after drilling of a number of wells. White Rose data (reviewed herein) may be the most relevant in this regard because they are the most recent.

- To date, the conclusions that the Study Team has seen drawn from the production EEM studies, are that there have been no significant effects on the variables that have been measured. Thus, it seems reasonable to conclude that a properly run exploration drilling program will produce effects that will be on the low end of the scale and difficult to measure; it will certainly not create any significant effects on the marine environment.

- If drilling EEM was required, perhaps because of drilling with a new technology or in a potentially sensitive area, then one or a combination of the production EEM design(s) would provide a good starting point.

7.0 Discussion

7.1. Decision Process

A 'decision tree' approach to EEM was suggested by several stakeholders in both Nova Scotia and Newfoundland and Labrador. A potential 'decision tree' for exploratory drilling EEM is shown in Figure 7.1. This approach is a type of hybrid between the zoning approach used in the Gulf of Mexico, the generic EA advocated by some for Nova Scotia, and the highly targeted approach used in the US and Canadian Arctic.

7.2. Scenarios

After the drilling application and EA are submitted a decision should be made based on three scenarios appropriate to the East Coast (at least as far as experience to date dictates):

Scenario 1—Exploratory drilling of a single well in an area where data are sufficient to determine there are no issues requiring EEM. An example of this could include an exploratory well within (or immediately adjacent to) an area previously assessed in a detailed manner (e.g., the Terra Nova Development). Compliance monitoring would be conducted but no specific EEM is required. Opportunistic bird and mammal surveys (not, strictly speaking EEM) would be at the option of the Operator.

Scenario 2—There are two alternatives in this scenario:

(a) Shallow water (≤200-m) situation with no known sensitive issues but the area has not undergone an extensive EA in the recent past. [Note this 'shallow' designation would encompass the areas containing all East Coast production developments done to date.]. 'Before and after' surveys would be 'piggy-backed' onto existing geophysical site surveys routinely conducted as part of the site permitting and clearance process. Video surveys/interpretation, opportunistic grabs with Van Veen or Shipek grabs, and bird and mammal shipboard surveys can be conducted with little additional cost to the Operator. This would not only provide EEM data but also assist the Operator in addressing any potential liability issues. A final report accessible to the public would be prepared.

(b) Deep water (>200-m) situation with no known sensitive issues but the area has not undergone extensive EA in the recent past. Deep water may require more detailed work-ups than shallow areas if the level of knowledge is much lower for the deep water areas. 'Before and after' surveys would be 'piggy-backed' onto existing geophysical site surveys routinely conducted as part of the site clearance process. Side scan sonar (or equivalent) surveys and interpretation, video surveys/interpretation, grab sampling with Van Veens or box corers, and bird and mammal shipboard surveys can be conducted with little additional cost to the Operator. A final report accessible to the public would be prepared.

Scenario 3—Sensitive areas (shallow or deep). Surveys and sampling would be conducted as per Scenario 2 (above) plus custom-designed surveys or monitoring program. It is anticipated that this scenario would primarily be associated with marine mammal areas (e.g., The Gully). The custom monitoring could include additional or more detailed or systematic surveys and such specialty components as noise measurements A final report accessible to the public would be prepared.

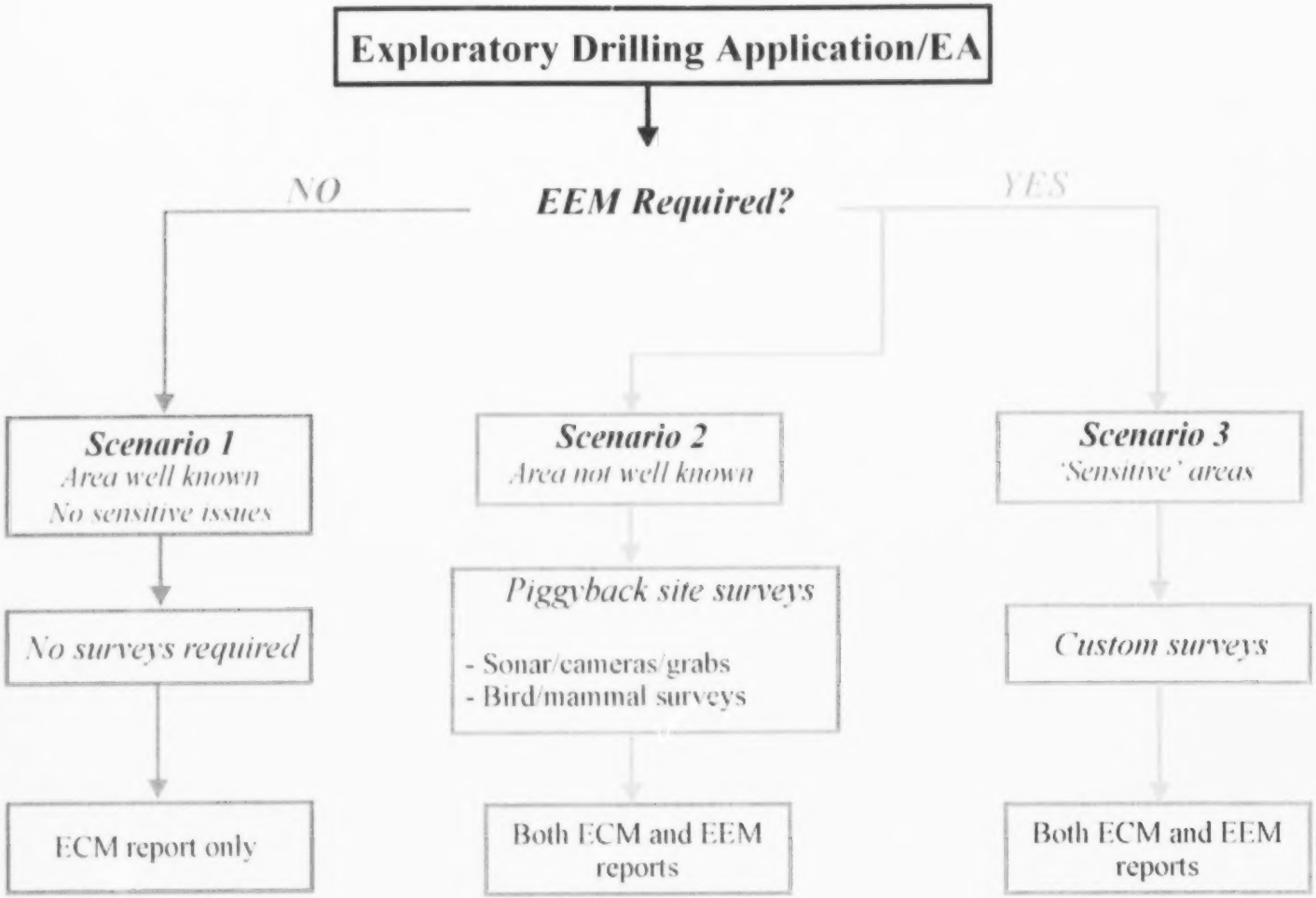

Figure 7.1. Proposed Decision Tree for Exploratory Drilling EEM.

Note that sampling on-site for Scenario 2 would be 'opportunistic' in the sense that logistics would depend upon operational site survey logistics. Typically (but not always, if there are good 3-D seismic data available prior to drilling) the well site surveys would consist of sonar, ROV, and grab work prior to drilling and at least ROV surveys post-drilling.

More detail on approaches for the different scenarios is contained in the following sections.

7.3. Shallow vs. Deep Wells

For the purposes of this report we have arbitrarily defined 'shallow' as 200-m or less, which covers the continental shelf of the East Coast and includes all presently producing wells. Based on the review and consultations, and well depths to present, we conclude that while environmental conditions and species composition may differ somewhat, there are no overwhelming differences between shallow and deep as far as EEM study design for the East Coast is concerned (other than those few exceptions noted here). Any effects will be similar although perhaps somewhat different in magnitude or distribution. For example, WBM released at the surface at a deep location may disperse more widely than a shallow location although currents would play a large role as well in either location. Sound propagation from the drill rig may also be somewhat different depending upon depth to the bottom, but again other environmental factors such as temperature and salinity would also be important.

In terms of East Coast issues, the main one strictly related to depth would be the presence or absence of any special benthic communities such as deep water corals. [This is analogous to the situation in the Gulf of Mexico where there is concern for special benthic communities such as coral outcrops and chemosynthetic communities.]

In general, we conclude that location is much more important than water depth in designing EEM programs. In other words, proximity to special areas such as The Gully or concentrations of deep water corals is much more important than whether a well is shallow or deep.

7.4. Potential EEM Designs

The recommended study designs to address the three scenarios are provided below. They have intentionally been left general in order to avoid being too prescriptive and to allow for specific circumstances.

7.4.1. Scenario 1—No EEM

In this scenario, data are sufficient and thus no EEM data are required. However, compliance monitoring (ECM) must be conducted according to *OWTG*. At least a summary of the compliance monitoring data should be made available to the public after a reasonable period of time for QA/QC.

The cost for EEM under this scenario is nil but there would be some cost involved in summarizing the ECM data in a suitable format, understandable by a knowledgeable layperson.

7.4.2. Scenario 2—No Known Sensitive Issues but Few Data

7.4.2.1. Shallow Water or On-shelf Wells

This scenario assumes a relatively low level of environmental concern, albeit more than for an area that has been intensively studied. Studies would be 'piggy-backed' onto routine well site surveys and sampling would be opportunistic. The primary goal will be to provide some level of 'assurance' that the bottom environment has not been unduly impacted by the drilling activity.

7.4.2.1.1. Objectives

Objectives would be to gain as much information as possible before and after drilling on the following top priority variables

- Sediment grain size (useful for both EA and interpretation of EEM data)
- Redox potential (an indicator of environmental quality)
- Barium (a drilling 'fingerprint' metal)
- Benthic macro-fauna (video survey)

Sediment samples could be archived or analyzed for other potential contaminants such as TOC/TIC, metal and petroleum hydrocarbons at the Operator's discretion. Infauna could be identified if it was deemed to be of use.

Bird and mammal surveys from the rig and/or supply boats would be opportunistic and at the Operators' discretion.

7.4.2.1.2. Sampling Design

It is recommended that sampling be conducted along the axes of dominant bottom currents if they are known. Because it is highly likely in most cases that there will not be enough bottom current data, it is suggested that a radial transect approach such as commonly used now is probably the best design.

Numbers of samples can be opportunistic and somewhat at the Operators' discretion but it is suggested that on the order of 15 sediment samples be collected.

Video surveys should be collected along the radials and interpreted for substrate and benthic macro-fauna (and flora if present).

7.4.2.1.3. Equipment and Methodology

Sediment samples would be collected by standard methods using a grab or corer. Van Veen and/or Shipek grabs are typically used for the routine well site surveys so the use of this equipment would not incur extra costs.

Video surveys would be conducted by the equipment and technician normally aboard for the well site surveys and thus would not incur significant extra costs.

Sampling, surveys, data collection, interpretation and reporting should be under the direction of an experienced marine biologist.

Some preliminary draft survey protocols for bird and mammal surveys are contained in Appendix IV. The reader is also referred to a previous ESRF report on seabird monitoring (Montevecchi et al. 1999). Note that LGL Limited is presently completing protocols under the ESRF.

7.4.2.1.4. Costs

There may be large variations in the costs of EEM for Scenario 2 with the largest variable being the logistic costs. Also, cruise length and marine bird and mammal surveys could be quite variable which would affect personnel time. As this scenario is considered 'opportunistic' certain logistic costs such as major sampling equipment, ship time, video equipment and technician may not be included. A list of potential cost items is provided below

Benthos, Sediment Sampling

Field Mobilization, Implementation, Demobilization

Personnel
Grabs
Video
Disbursements

Laboratory Analyses

20 (+/-) samples (particle size, TOC/TIC, metals, redox)

Data Analyses and Report

Personnel
Disbursements

Bird and Mammal Surveys

Personnel (1 observer – 30 (+/-) days)
Disbursements

Data Analyses and Report

Personnel
Disbursements

Total costs for this scenario are intermediate between Scenario 1 and Scenario 3.

7.4.2.2. Deep Water Wells

This part of the scenario assumes a potentially higher level of environmental concern than for shallow water, primarily because of the general lack of knowledge on deep water areas. Studies would be 'piggy-backed' onto routine well site surveys but sampling would be less opportunistic and more pre-planned than for shallow water. The primary goal will be to provide a higher level of assurance (than shallow water where more general knowledge is available) that the bottom environment has not been unduly impacted by the drilling activity.

7.4.2.2.1. Objectives

Objectives would be to gain as much information as possible before and after drilling on the following top priority variables

- Sediment grain size (useful for both EA and interpretation of EEM data)
- Redox potential (an indicator of environmental quality)
- Barium (a drilling 'fingerprint' metal)
- TOC/TIC
- Benthic macro-fauna (video survey)

Plus

- Side scan sonar surveys (or equivalent), including interpretation, to gain information on habitat (bottom topography, substrate, etc.)
- Grab or core samples collected in a more systematic manner

Sediment samples would be archived for possible analyzing for other potential contaminants such as metal and petroleum hydrocarbons at the Regulator's discretion. Infauna samples could be identified to various taxonomic levels if it was deemed to be of use.

Bird and marine mammal surveys would be conducted from the rig and/or the supply boats.

7.4.2.2.2. Sampling Design

It is recommended that sampling be conducted along the axes of dominant bottom currents if they are known. Because it is highly likely in most cases that there will not be enough bottom current data, it is recommended that a radial transect approach such as commonly used now be adopted.

A minimum of 30 sediment samples would be collected.

Video surveys should be collected along the radials and interpreted for substrate and benthic macro-fauna.

7.4.2.2.3. Equipment and Methods

Sediment samples would be collected by standard methods using a grab or corer. Van Veen and/or Shipek grabs are typically used for the routine well site surveys so the use of this equipment would not incur extra costs.

Video surveys would be conducted by the equipment and technician normally aboard for the well site surveys and thus would not incur significant extra costs. The 'drop camera' would be a deep sea camera capable of taking high resolution photos of the sea bottom (e.g., Benthos Deep Sea Camera or equivalent).

Sampling, surveys, data collection, interpretation and reporting would be under the direction of an experienced marine biologist.

Some preliminary draft survey protocols for bird and mammal surveys are contained in Appendix IV. See also Montevecchi et al. (1999). LGL Limited is presently developing protocols for the ESRF.

7.4.2.2.4. Costs

There may be large variations in the costs of EEM for deep water with the largest variable being the logistic costs. Also, cruise length and marine bird and mammal surveys could be quite variable which would affect personnel time. Because this is a 'piggy-back' survey, logistic costs such as major sampling equipment, ship time, video equipment and technician may not be included. However, because of a more systematic sampling approach and the dedicated 'drop camera' work, it is likely that an extra day or two ship time will be required. A list of potential cost items is provided below.

Benthos, Sediment Sampling

Field Mobilization, Implementation, Demobilization

Personnel
Grabs
Video
Drop camera rental
Disbursements

Laboratory Analyses

30 (+/-) samples (particle size, TOC/TIC, metals, redox)

Data Analyses and Report

Personnel
Disbursements

Bird and Mammal Surveys

Personnel (1 observers – 40 (+/-) days)
Disbursements

Data Analyses and Report

Personnel
Disbursements

The costs for deep water work would be approximately twice those of shallow water EEM.

7.4.3. Scenario 3—Sensitive Areas

This scenario involves all of Scenario 2 plus custom-designed surveys (see above for objectives, designs, equipment, methods, and costing). We cannot 'pre-judge' what might be designed for specific areas of interest but these often involve marine mammal and noise issues. Some suggested methods for marine mammal and acoustic monitoring are contained in Moulton et al. (2003).

7.4.3.1. Costs

Costs for definitive studies on marine mammal and noise issues are substantial and may be on the order of $250,000 to $500,000 range or more. Costs for other potential studies on, for example, deep sea corals could also easily reach those levels.

7.4.4. Regional EEM

It is beyond the scope of a document dealing with single exploratory well scenarios to consider regional environmental assessment or regional EEM. Nonetheless, as the oil industry expands off the East Coast, regional issues will likely move to the forefront. As part of regional studies, it has been suggested by some of the stakeholders that permanent reference stations or transects be established. It may be advantageous to 'piggy-back' these reference stations on existing long term ones such as Station 27 or the 'Bonavista Transect' off Newfoundland or the 'Halifax Line' or 'Gully Station' off Nova Scotia. Such stations would serve as useful long term reference or 'control' points for any studies examining the effects of exploratory wells.

7.5. Potential EEM Support Studies

The decision framework and approach to study designs under different situations has been provided in previous sections. More specific study suggestions are presented in this section. Special studies in support of EA or EEM to deal with emerging issues may be advisable. It became obvious to us during the course of this study, that there are still some 'issues on the table' that could be addressed by 'stand-alone' studies. For example, what is the actual (not theoretical or modeled) area smothered by the disposal of drill cuttings and mud on the sea floor, or what do the noise 'envelopes' around the different types of rigs or supply boats look like. Such studies would provide useful support to both EA and EEM, and help in setting priorities and designing programs. We have termed this an 'emerging issues scenario' because past experience has shown us that as some concerns diminish either through

accumulation of data or by mitigation, other new ones tend to appear. Such special or supporting studies are not strictly EEM but they may start as EEM studies and then evolve into special studies or they may be specifically designed to aid EEM.

Nova Scotia and Newfoundland suggested studies are presented separately below because the issues and level of concern as expressed during the consultations were somewhat different.

7.5.1. Nova Scotia Studies

A study or series of studies could be conducted to monitor a suite of benthic variables at a minimum of four different locations representing four distinct habitats.

7.5.1.1. Rationale

As reviewed and discussed in previous sections (see Sections 2.0 to 4.0), it is clear that even though there has been considerable monitoring of multi-well situations, the issue of the extent and degree of benthic habitat alteration or contamination from a single well still appears to be outstanding. On the one hand it seems reasonable to assume that if large multi-well developments do not produce important or significant effects then single wells also will not produce them. On the other hand, there have been suggestions that the magnitude of surface enrichments from drilling discharges among sites within similar depositional environments (i.e., judged by water depth) was similar regardless of the number of wells drilled (CSA *in* Kennicutt et al. 1996a). Large scale reviews of the environmental effects of offshore oil and gas development have identified the effects of discharges of produced water and accumulations of drill mud and cuttings as the key research priorities (see Peterson et al. 1996). There continues to be a relatively high level of concern related to offshore drilling in Nova Scotia waters compared to Newfoundland waters. One of the primary concerns is with effects on benthos, particularly shellfish. In addition, there is potential for drilling in a variety of habitats containing a range of substrates and physical oceanographic regimes. To date, there are four potential exploration drilling scenarios for Nova Scotia waters: (1) on a bank (i.e., shallow water, generally sandy-bottom environments), (2) on the slope (≥200m), (3) in a gully (i.e., deep valley within the shelf area), and (4) deep water off the slope. The two North Triumph wells have been suggested as likely candidate locations for a shallow water site and it may be useful to re-examine any existing data for this area.

It is suggested that the following EEM support studies be conducted until variables reach background levels or the issue is settled. The results will be of use to both future impact assessments as well as monitoring programs.

7.5.1.2. Objectives

The objectives of the Nova Scotia studies would be:

- To test the null hypothesis that environmental effects (as measured by sediment chemistry, benthic communities, and toxicity) from exploratory drilling do not extend beyond 500-m from a single exploratory well,

- To further test and validate the **bblt** model,

- To determine the physical area (s) of effects, and

- To determine the longevity of any effects.

7.5.1.3. Methodology

It is suggested that the Chapman's sediment quality triad (SQT) approach as advocated by Green and Montagna (1996) is the most effective methodology. This approach uses data from sediment chemistry, benthic infauna, and toxicology that have been collected at the same time to assess environmental quality. Sampling should be conducted with stainless steel box corer or bottom grab. The following variables are suggested as the top priority ones; others could be added (e.g., shellfish body burdens, enzyme activity, if appropriate).

Sediment chemistry

- Total PAH
- Total alkanes
- Particle size
- Total inorganic carbon (TIC)
- Total organic carbon (TOC)
- Redox potential
- Metals (particularly Ba*)

*Note that care should be taken with the selection of extraction method because results can differ by orders of magnitude (Hartley 1996 *in* Holdway 2002).

Benthic infauna

- Identify at least to major taxa
- Determine abundance and biomass

Toxicology

- Microtox™ (bacterial bioluminescence)

Optional Components

- Amphipod survival test (if Microtox™ tests positive)
- Body burdens of petroleum hydrocarbons and/or metals in indigenous shellfish

The above variables are commonly collected during East Coast EEM studies (e.g., Husky 2001a,b).

7.5.1.4. Sampling Design

The suggested sampling design is one that uses radial transects with sampling conducted at appropriate intervals such as 50, 100, 200, 500, 3,000-m (or something similar) as was used during the major Gulf of Mexico platform study (GOOMEX) (see Carr et al. 1996b; Ellis et al. 1996; Green and Montagna 1996; Kennicutt et al. 1996a,b; McDonald et al. 1996; Montagna and Harper 1996; Husky 2001a,b, and others).

The radials should be set along cardinal points unless data are available on prevailing bottom currents where it would be advisable to orient at least one transect along the axis of the predominant current.

7.5.1.5. Numbers of Samples

The decision on the numbers of samples to be collected is a crucial one because, if too few, then validity is questionable; if too many, then costs become too high relative to the value of the data. If the intention is to describe in detail the situation at one individual site, then one would take large numbers of samples at few sites (see Green and Montagna 1996). However, we believe that our situation calls for generalizations about drilling in particular areas so that once the study is complete, results can be applied to future exploration without the need for additional sampling. If this is the case, then it would be better to take potentially fewer samples at one site but sample more sites, potentially as many as 12 sites per area (Green and Montagna 1996). One of the key findings of Ellis (1996) during the GOOMEX study was the highly platform-specific nature of environmental variables and associated macro-epifaunal communities. It is recognized that this may be considered a large number of sites but the data can be assembled over time; not all 12 sites have to be done immediately. Also, there also may be economies to be obtained by reducing the numbers of sampling sites along each transect, for example, by analyzing near field vs. far-field effects (Green and Montagna 1996).

The actual number of samples to be collected will have to be determined after a more detailed examination of environmental conditions at each site, once the likely sites are known. This determination should made using statistical techniques such as those outlined in Green (1979, 1984) and in consultation with the C-NSOPB. In order to gain some appreciation of the order of magnitude--Husky (2001b) concluded that three replicate samples (subsequently combined into one) collected at about 50 stations was sufficient for their EEM purposes at White Rose.

7.5.1.6. Data Analyses

A priori power analysis should be used to aid in determining the numbers of samples required (e.g., Zar 1998). Multivariate analysis is the preferred methodology for analyzing SQT data (R. Green, pers. comm.).

7.5.2. Newfoundland and Labrador Studies

It is suggested that existing data from Terra Nova and White Rose be assembled and re-analyzed for the purposes of assessing the effects from single exploratory wells. There is now a considerable amount of data (both baseline and EEM) that can be related to well locations, timing, volumes and types of drilling mud used, water depths, substrate types, currents, and so forth (e.g., Petro-Canada 1999; Husky 2001b, 2003a,b, and others). Consideration should also be given to re-analyzing the Hibernia EEM data, or at

least the baseline data although the Hibernia situation can now be considered atypical for the East Coast. In the case of Terra Nova, there may be some confounding of factors if data after production started is used.

Rationale, objectives, previous methodology, and data analysis procedures are all virtually identical to the above (Nova Scotia studies above).

7.6. Ongoing ESRF Studies

It should be noted that the ESRF has a number of ongoing studies that should be of direct relevance to addressing some of the issues discussed in previous sections (see ESRF 2003). For example, the following studies are ongoing:

- *Field Verification of Benthic Boundary Layer Modelling Effects.* This DFO study is using existing SOEI data to test the benthic boundary layer models. [Report has been submitted, Hannah et al. 2003.]

- *Deep Water Benthic Community Study.* This study by DFO is using video and photography techniques to obtain information on deep water corals. The final report was due in April 2004.

- *Mesocosm and Laboratory Study of Effects of Drill Cuttings.* This study, also by DFO, concerned biological effects, recovery rates, physical vs. chemical effects, and possible interactions of several rig sites. Final report was due in March 2003.

- *Seabird Attraction to Production Installations: Instrument-Based Approaches.* An RFP will be issued in 2003.

8.0 Conclusions

The primary conclusions of this study were:

2. There are notable differences between the different regions in the East Coast concerning the need for, and the amount required of, EEM. However, most stakeholders agreed that the concern was much less for the single exploratory well than for a production development.

   Some important common points of view found in both areas are listed below.

   - **Level of concern with exploration drilling**. Although there were some exceptions, most people had a much lower level of concern for the environmental effects of a single exploratory well than for a production development.

   - **Assurance monitoring.** While some argued strongly for extensive statistical work, there still was a common thread that most people wanted some level of reassurance that a specific site was not being unduly affected. A number of people suggested some camera drops and some grab samples might be enough to accomplish the goal of providing a suitable level of comfort.

   - **Testing EA.** A number of participants suggested that one of the key functions of a monitoring program is to test predictions, and in some cases modeling, that were conducted during the EA process. A potential corollary of this attitude is the suggestion by some that one or several wells should be selected as 'test cases' and monitored possibly in aid of a Class or Generic EA approach. This would provide rationale for including or excluding monitoring variables for future individual wells.

   - **Biological effects**. With some exceptions, most felt that any monitoring programs should focus on biological effects as opposed to simply 'shopping' for increases (however slight) of potential contaminants.

   - **Birds and mammals**. Many agreed that there were potentially important issues in regard to marine birds and mammals. However, it was also pointed out by a number of people that routine surveys conducted from the rig or supply boats do not necessarily constitute any monitoring of effects *per se*.

   - **Site specifics.** Local and site specific issues must be considered in the design and conduct of any EEM. This was a virtually universal comment. There is awareness in both locations of some potential for different issues in deep versus shallow drilling scenarios. To date, however, the depth differences have been most apparent off Nova Scotia where most wells have been drilled in shallow water or increasingly in deepwater.

- **Data availability.** Almost everyone we talked to stated that availability of EEM data is an important issue. At present, the *Atlantic Accord* allows a development to hold the EEM data confidential for five years. In fact, availability of data was an issue with the conduct of this study.

- **Cumulative effects.** While many were not particularly concerned with the effects of one exploratory well, they suggested that a large number of single wells could be an issue, particularly if they were within a relatively small geographic and/or time frame. On the other hand, no one had any solutions to this problem.

3. Existing offshore production EEM programs appear to be working reasonably well and results are at least partially relevant to the design and conduct of EEM for exploratory wells.

   - Aside from a large oil blowout (a very unlikely event according to previous EAs) and a few other special cases, any effects from an exploratory situation are of much less concern than a production scenario.

   - In general, the production EEM programs completed to date are viewed as adequate for confirming EA predictions and in providing a level of assurance that the East Coast marine ecosystems have not been significantly affected to date. They have also served as testing of techniques for use in EEM off the East Coast.

   - Baseline studies conducted by Hibernia, Terra Nova, and White Rose can provide valuable insights into the effects of drilling because these studies were done at varying periods of time after drilling of a number of wells. White Rose data (reviewed herein) may be the most relevant in this regard because they are the most recent. These data should be re-examined with this different objective of teasing out effects of exploration, if any.

   - To date, the conclusions that the Study Team has seen drawn from the production EEM studies, are that there have been no significant effects on the variables that have been measured. Thus, it seems reasonable to conclude that a properly run exploration drilling program will produce effects that will be on the low end of the scale and difficult to measure; it will certainly not create any significant effects on the marine environment.

   - If drilling EEM was required, perhaps because of drilling with a new technology or in a potentially sensitive area, then one or a combination of the production EEM design(s) would provide a good starting point.

4. EEM is not warranted for the single exploratory well in all situations; for example, in non-sensitive areas that are well known. Compliance monitoring would still be conducted and reported.

5. A potential 'decision tree' has been suggested for different levels of EEM based on three different scenarios:

(a) Scenario 1—well known area with no sensitive issues. Compliance monitoring but no EEM would be conducted.

(b) Scenario 2—shallow or deep areas with no known sensitive issues. Opportunistic EEM surveys of sediments, benthos, seabirds and marine mammals would be 'piggy-backed' on existing logistics.

(c) Scenario 3—sensitive areas. Custom EEM surveys would be required.

6. Most EEM for an exploratory well can be 'piggy-backed' onto existing programs such as well site surveys in order to minimize costs.

7. 'Special' EEM support studies of selected existing data and new data could be collected to further refine, and potentially reduce EEM in the future.

9.0 Literature Cited

Borgmann, U., W.P. Norwood, T.B. Reynoldson and F. Rosa. 2001. Identifying cause in sediment assessments: bioavailability and the sediment quality Triad. Can. J. Fish. Aquat. Sci. 58: 950-960.

Breeze, H., D.S. Davis, M. Butler and V. Kostylev. 1997. Distribution and status of deep sea corals off Nova Scotia. Marine Issues Committee Special Publication No. 1, Ecology Action Centre. 58 p.

Cantelmo, F.R., M.E. Tagatz and K.R. Rao. 1979. Effect of barite on meiofauna in a flow-through experimental system. *Mar. Environ. Res.*, 2: 301-309.

CAPP. 1999. Estimation of direct human resource requirements offshore exploration and production Newfoundland and Nova Scotia 2000-2010. Report by the Canadian Association of Petroleum Producers.

CAPP. 2001a. Safety zones. Canadian Association of Petroleum Producers. 7 p. + App.

CAPP. 2001b. Offshore drilling waste management review. Canadian Association of Petroleum Producers Technical Report 2001-0007. 194 p. + App.

Carr, R.S., D.C. Chapman, C.L. Howard and J.M. Biedenbach. 1996a. Sediment quality triad assessment survey of the Galveston Bay, Texas system. Ecotoxicology 5, pp. 341-364.

Carr, R.S., D.C. Chapman, B.J. Presley, J.M. Biedenbach, L. Robertson, P. Boothe, R. Kilada, T. Wade, and P. Montagna. 1996b. Sediment porewater toxicity assessment studies in the vicinity of offshore oil and gas production platforms in the Gulf of Mexico. Can. J. Fish. Aquat. Sci. 53: 2618-2628.

Chapman, P.M., R.N. Dexter, H.A. Anderson and E.A. Power. 1991. Evaluation of effects associated with an oil platform, using the Sediment Quality Triad. Toxicol. Chem. 10: 407-424.

C-NOPB. 2002. Offshore waste treatment guidelines. Prepared by National Energy Board, Canada – Newfoundland Offshore Petroleum Board and the Canada – Nova Scotia Offshore Petroleum Board. 11 p + App.

Conklin, P.J., D.G. Doughtie and K.R. Rao. 1980. Effects of barite and used drilling muds on crustaceans, with particular reference to the grass shrimp, Palaemonetes pugio. *In*: Symposium, Research on Environmental Fate and Effects of Drilling Fluids and Cuttings, Lake Buena Vista, Florida, January 21-24, 1980. API, Washington, D.C.

Cranford, P.J. and D.C. Gordon Jr. 1992. The influence of dilute clay suspensions on sea scallop (*Placopecten magellicanus*) feeding activity and tissue growth. Neth. J. Sea Res. 30:107-120.

Cranford, P.J., D.C. Gordon, K. Lee, S.L. Armsworthy and G.H. Tremblay. 1999. Chronic toxicity and physical disturbance effects of water- and oil-based drilling fluids and some major constituents on adult sea scallops (*Placopecten magellanicus*). *Mar. Environ. Res.*, 48: 225-256.

Cranford, P.J., K. Lee, J.W. Loder, T.G. Milligan, D.K. Muschenheim and J.F. Payne. 2001. Scientific considerations and results relevant to the review of the 1996 offshore waste treatment guidelines. *Can. Tech. Rep. Fish. Aquat. Sci.*, 2364.

d'Entremont, A. 2003. Environmental effects monitoring results of offshore wells. CAPP Powerpoint Presentation to RAC Sub-committee.

Davies, J.M., J.M. Addy, R.A. Blackman, J.R. Blanchards, J.E. Ferbrache, D.C. Moore, H.J. Sommerville, A. Whitehead and T. Wilkinson. 1984. Environmental effects of the use of oil-based drilling muds in the North Sea. *Mar. Poll. Bull.*, 15: 363-370.

Ellis, M.S., E.A. Wilson-Ormand, and E.N. Powell. 1996. Effects of gas-producing platforms on continental shelf macroepifauna in the northwestern Gulf of Mexico: abundance and size structure. Can. J. Fish. Aquat. Sci. 53: 2589-2605.

Environmental Protection Agency (EPA). 2000. Environmental assessment of final effluent limitations guidelines and standards for synthetic-based drilling fluids and other non-aqueous drilling fluids in the oil and gas extraction point source category. EPA-821-B-00-014, December 2000.

ESRF. 2003. Environmental studies research funds annual report 2002. National Energy Board, Calgary. 23 p.

Fechhelm, R.G., B.J. Gallaway, G.F. Hubbard, S. MacLean and L.R. Martin. 2001. Opportunistic sampling at a deep-water synthetic drilling fluid discharge site in the Gulf of Mexico. Gulf of Mexico Science. 2: 97-106.

Gallaway, B.J., L.R. Martin, R.L. Howard, G.S. Boland and G.D. Dennis. 1981. Effects on artificial reef and demersal fish and macrocrustacean communities. In: Environmental Effects of Offshore Oil Production: the Buccanear Gas and Oilfield Study. Middleditch, BS, 1981.

GESAMP (IMO/FAO/UNESCO/WHO/IAEA/UN/UNEP Group of Experts on the Scientific Aspects of Marine Pollution). 1993. Impact of oil and related chemicals and wastes on the marine environment. *Rep. Stud. GESAMP*, 50, 180 p.

Green, R.H. 1979. Sampling Design and Statistical Methods for Environmental Biologists. Wiley, New York.

Green, R.H. 1984. Statistical and nonstatistical considerations for environmental monitoring studies. Environ. Monit. Assess. 4: 293-301.

Green, R.H. and P. Montagna. 1996. Implications for monitoring: study designs and interpretation of results. Can. J. Fish. Aquat. Sci .53: 2629-2636.

Grizzle, J.M. 1986. Lesions in fishes captured near drilling platforms in the Gulf of Mexico. *Mar. Environ. Res.*, 18: 267-276.

Hannah, C.G., A. Drozdowski, D.K. Muschenheim, J.W. Loder, S. Belford, and M. MacNeil. 2003. Evaluation of drilling mud dispersion models at SOEI Tier I Sites: Part 1 North Triumph, Fall 1999. Can. Tech. Rep. Hydrography and Ocean Sciences 232: 1-51.

HMDC 1995. Hibernia baseline environmental effects monitoring data report October, 1995. Report by Hibernia Management Development Company, St. John's, NL. 122 p. + List of Errata + November 23, 1995 Addenda + App.

Holdway, D.A. 2002. The acute and chronic effects of wastes associated with offshore oil and gas production on temperate and tropical marine ecological processes. Mar. Poll. Bull. 44: 185-203.

Husky. 2000. White Rose Oilfield Comprehensive Study. Submitted by Husky Oil Operations Limited, St. John's, NL.

Husky. 2001a. White Rose Oilfield Comprehensive Study Supplemental Report. Submitted by Husky Oil Operations Limited, St. John's, NL. 265 p. + App.

Husky. 2001b. White Rose baseline characterization data report June 2001. Prepared by Jacques Whitford Environment Limited for Husky Oil Operations Limited, St. John's, NL. 109 p. + App.

Husky. 2002. Husky Jeanne d'Arc Basin Exploration Drilling Program Project Description and Environmental Assessment. Prepared by LGL Limited, Oceans Limited, Provincial Airlines Limited, and S.R. Ross Environmental Research Ltd. for Husky Oil Operations Limited, St. John's, NL. 179 p.

Husky. 2003a. Husky Lewis Hill Prospect Exploration Drilling Program Environmental Assessment. Prepared by LGL Limited, Oceans Limited, Provincial Airlines Limited, and S.R. Ross Environmental Research Ltd. for Husky Oil Operations Limited, St. John's, NL. 324 p.

Husky. 2003b. White Rose baseline addendum draft report January 2003. Prepared by Jacques Whitford Environment Limited for Husky Oil Operations Limited, St. John's, NL. 14 p. + App.

ICES (International Council of the Exploration of the Sea) Workshop. 2002. Biological Effects in Pelagic Ecosystems (BECPELAG), Copenhagen.

JWE Ltd. (Jacques Whitford Environmental Limited). 1998. Terra Nova baseline characterisation data report, prepared for Petro-Canada, 1998.

JWE Ltd. (Jacques Whitford Environmental Limited). 2000. White Rose baseline characterisation data report, prepared for Husky, 2000.

Kennicutt II, M.C., P.N. Boothe, T.L. Wade, S.T. Sweet, R. Rezak, F.J. Kelly, J.M. Brooks, B.J. Presley, and D.A. Wiesenberg. 1996a. Geochemical patterns in sediments near offshore production platforms. Can. J. Fish. Aquat. Sci. 53: 2554-2566.

Kennicutt II, M.C., R.H. Green, P. Montagna, and P.F. Roscigno. 1996b. Gulf of Mexico Offshore Operations Monitoring Experiment (GOOMEX), Phase I: Sublethal responses to contaminant exposure—introduction and overview. Can. J. Fish. Aquat. Sci. 53: 2540-2553.

Kingston, P.F. 1992. Impact of offshore oil production installations on the benthos of the North Sea. ICES J. Mar. Sci. 49: 45-52.

Kostylev, V., B.J. Todd, G.B.J. Fader, R.C. Courtney, G.D.M. Cameron, and R.A. Pickrill. 2001. Benthic habitat mapping on the Scotian Shelf based on multibeam bathymetry, surficial geology and seafloor photographs. Mar. Ecol. Prog. Ser. 219: 121-137.

LGL Ltd. 2003. Orphan Basin Strategic Environmental Assessment. Report by LGL Limited, St. John's, NL, to Canada-Newfoundland Offshore Petroleum Board. 229 p.

Mathieu, A. 2002. Potential impacts of exploratory drilling on the health and productivity of finfish and shellfish: A review. Report by Oceans Ltd. prepared for LGL Limited. 25 p.

McDonald, S.J., K.L. Willett, J. Thomsen, K.B. Beatty, K. Connor, T.R. Narasimhan, C.M. Erickson, and S.H. Safe. 1996. Sublethal detoxification responses to contaminant exposure associated with offshore production platforms. Can. J. Fish. Aquat. Sci. 53: 2606-2617.

MMS. 2000. Environmental impacts of synthetic based drilling fluids. U.S. Dept. Interior Minerals Management Service Gulf of Mexico OCS region. OCS Study MMS 2000-064. 121 p.

Montagna, P.A. and D.E. Harper, Jr. 1996. Benthic infaunal long-term response to offshore production platforms in the Gulf of Mexico. Can. J. Fish. Aquat. Sci. 53: 2567-2588.

Montagna, P.A., S.C. Jarvis, and M.C. Kennicutt, II. 2002. Distinguishing between contaminant and reef effects on meiofauna near offshore hydrocarbon platforms in the Gulf of Mexico. Can. J. Fish. Aquat. Sci. 59: 1584-1592.

Montevecchi, W.A., F.K. Wiese, G. Davoren, A.W. Diamond, F. Huettmann, and J. Linke. 1999. Seabird attraction to offshore platforms and seabird monitoring from offshore support vessels and other ships: literature review and monitoring designs. Prepared for Canadian Association of Petroleum Producers.

Moulton, V.D., R.A. Davis, J.A. Cook, M. Austin, M.L. Reece, S.A. Martin, A. MacGillivray, D. Hannay, and M.W. Fitzgerald. 2003. Environmental assessment of Marathon Canada Limited's 3-D seismic program on the Scotian Slope, 2003. LGL Rep. SA744-1. Rep. by LGL Limited, St. John's, Newfoundland, and Greeneridge Sciences Inc., Santa Barbara, CA, for Marathon Canada Ltd., Halifax, Nova Scotia. 173 p. + Appendices.

Muschenheim, D.K. and T.G. Milligan. 1996. Flocculation and accumulation of fine drilling waste particulates on the Scotian shelf (Canada). *Mar. Poll. Bull.*, 32, 10: 740-745.

National Academy of Science (NAS). 1983. Drilling discharges in the marine environment. Panel on Assessment of Fates and Effects of Drilling Fluids and Cuttings in the Marine Environment, Marine Board, Commission on Engineering and Technical Systems, National Research Council, National Academy Press, Washington, D.C., 1983.

NEB, C-NOPB and C-NSOPB. 2002. Offshore waste treatment guidelines. National Energy Board, Canada-Newfoundland Offshore Petroleum Board, and Canada-Nova Scotia Offshore Petroleum Board. 21 p.

NEB, C-NOPB and C-NSOPB. 1999. Guidelines respecting the selection of chemicals intended to be used in conjunction with offshore drilling and production activities on frontier lands. Prepared by National Energy Board, Canada – Newfoundland Offshore Petroleum Board and the, Canada – Nova Scotia Offshore Petroleum Board. 16 p.

Neff, J.M., M. Bothner, N. Maciolek and J. Grassle. 1989. Impacts of Exploratory drilling for oil and gas on the benthic environment of Georges Bank. *Mar. Environ. Res.*, 27, 2: 77-114.

Neff, J.M., S. McKelvie and R.C. Ayers. 2000. Environmental impacts of synthetic based drilling fluids. OCS Study, MMS 200-064, published by U.S. Dept of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, August 2000.

NORDCO. 1983. Study of residual toxicity and debris on Hibernia P-15, B-08 and K-18 wellsites. Rep. for Department of the Environment, Environmental Protection Service.

Olsgard, F. and J.S. Gray. 1995. A comprehensive analysis of the effects of offshore oil and gas exploration and production on the benthic communities of the Norwegian continental shelf. *Mar. Ecol. Prog. Ser.*, 122: 277-306.

Payne, J.F., C. Andrews, S. Whiteway and K. Lee. 2001a. Definition of sediment toxicity zones around oil development sites: Dose response relationships for the monitoring surrogates Microtox^{r} and amphipods, exposed to Hibernia source cuttings containing a synthetic base oil. *Can. Manuscr. Rep. Fish. Aquat. Sci.*, No 2577, vi + 10 p.

Payne, J.F., L Fancey, C. Andrews, J.D. Meade, F.M. Power, K. Lee, G. Veinott and A. Cook. 2001b. Laboratory exposures of invertebrate and vertebrate species to concentrations of IA-35 (Petro Canada) drill mud fluid, production water, and Hibernia drill mud cuttings. *Can. Manuscr. Rep. Fish. Aquat. Sci.*, No 2560, iv + 27 p.

Payne, J.F., L. Fancey, J. Hellou, M.J. King and G.L. Fletcher. 1995. Aliphatic hydrocarbons in sediments: a chronic toxicity study with winter flounder (*Pleuronectes americanus*) exposed to oil well drill cuttings. *Can. J. Fish. Aquat. Sci.*, 52: 2724-2735.

Peterson, C.H., M.C. Kennicutt II, R.H. Green, P. Montagna, D.E. Harper Jr., E.N. Powell, and P.F. Roscigno. 1996. Ecological consequences of environmental perturbations associated with offshore hydocarbon production: a perspective on long-term exposures in the Gulf of Mexico. *Can. J. Fish. Aquat. Sci.* 53: 2637-2654.

Petro-Canada 1999. Terra Nova Environmental Monitoring Program.

Stagg, R.M. 1998. The development of an international program for monitoring the biological effects of contaminants in the OSPAR convention area. *Mar. Environ. Res.*, 46, 1-5: 307-313.

Stagg, R.M., A. McIntosh and P. Mackie. 1995. Elevation of hepatic monooxygenase activity in the dab (*Limanda limanda L.*) in relation to environmental contamination with petroleum hydrocarbons in the northern North Sea. *Aquat. Toxicol.*, 33: 245-264.

Terrens, G.W., D. Gwyther, M.J. Keough and R.D. Tait. 1998. Environmental assessment of synthetic based drilling mud discharges to Bass Strait, Australia. SPE 46622, 1-14. *In:* 1998 SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production ; Caracas, Venezuela, 7-10 June 1998. Society of Petroleum Engineers, Inc. Richardson, TX.

Thomson, D.H., R.A. Davis, R. Bellore, E. Gonzalez, J. Christian, V. Moulton and R. Harris. 2000. Environmental assessment of exploration drilling off Nova Scotia. Report by LGL Limited for Canada-Nova Scotia Offshore Petroleum Board, Mobil Oil Canada Properties Ltd., Shell Canada Ltd., Imperial Oil Resources Ltd., Gulf Canada Resources Ltd., Chevron Canada Resources, PanCanadian Petroleum, Murphy Oil Ltd., and Norsk Hydro. 278 p.

Veale, L.O., A.S. Hill, S.J. Hawkins and A.R. Brand. 2000. Effects of long-term disturbance by commercial scallop fishing on subtidal epifaunal assemblages and habitats. *Mar. Biol.*, 137: 325-337.

Wassenberg, T.J., G. Dews and S.D. Cook. 2002. The impacts of fish trawls on megabenthos (sponges) on the Northwest shelf of Australia. *Fish. Res.*, 58: 141-151.

Watling, L., R.H. Findlay, L.M. Mayer and D.F. Schick. 2001. Impact on scallop drag on the sediment chemistry, microbiota and faunal assemblages of a shallow subtidal marine benthic community. *J. Sea Res.*, 46: 309-324.

Wilson-Ormond, E.A., M.S. Ellis and E.N. Powel. 1994. The effect of proximity to gas producing platforms on size, stage of reproductive development and health in shrimp and crabs. National Shellfisheries Association, Charleston, South Carolina, *Abstracts*, 1994 Annual Meeting, April 24-28: 306.

Zar, J. H. 1998. Biostatistical Analysis. 4th Edition. Prentice Hall, NJ. 663 p. + App.

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